Gravitational Lensing and Cosmic Shear with the SDSS Coadd

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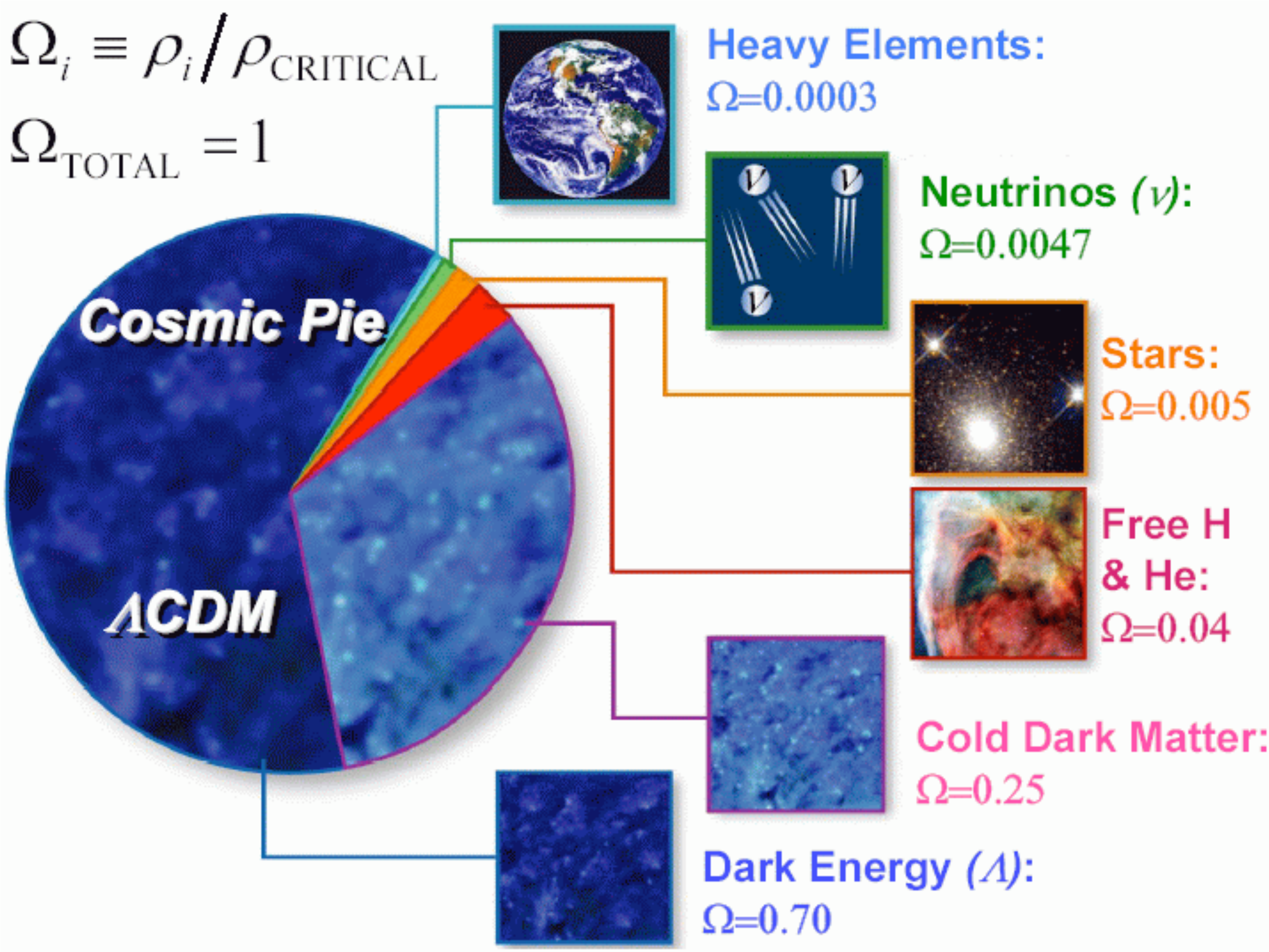
Outline

- Dark matter and introduction to gravitational lensing
- The SDSS coadd
- Coadd cosmic shear analysis
- Looking forward and conclusions

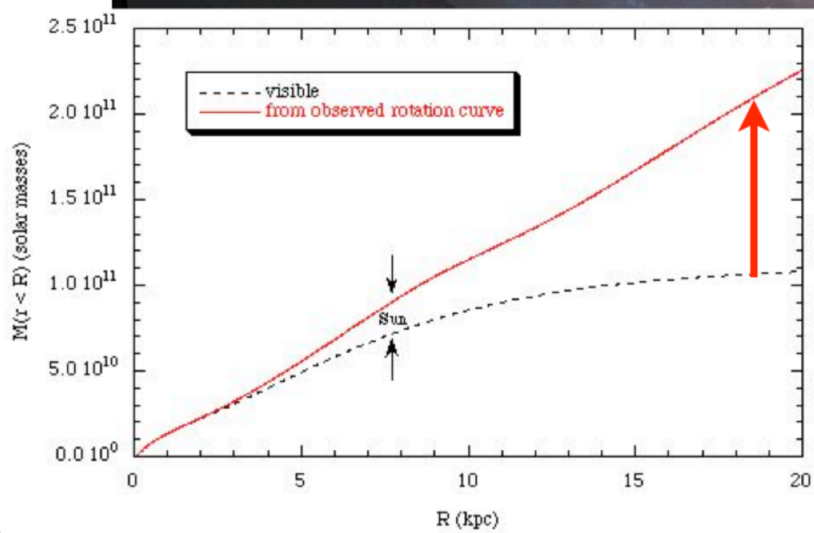

$\Omega_i \equiv \rho_i / \rho_{CRITICAL}$
$\Omega_{TOTAL} = 1$
Cosmic Pie
ΛCDM
Heavy Elements:
Ω=0.0003
Neutrinos (ν):
Ω=0.0047
ν
ν
ν
Stars:
Ω=0.005
Free H
& He:
Ω=0.04
Cold Dark Matter:
Ω=0.25
Dark Energy (Λ):
Ω=0.70

1933: Zwicky proposes the existence of "dark matter"

Zwicky discovered that the Coma cluster galaxies were moving much faster than expected

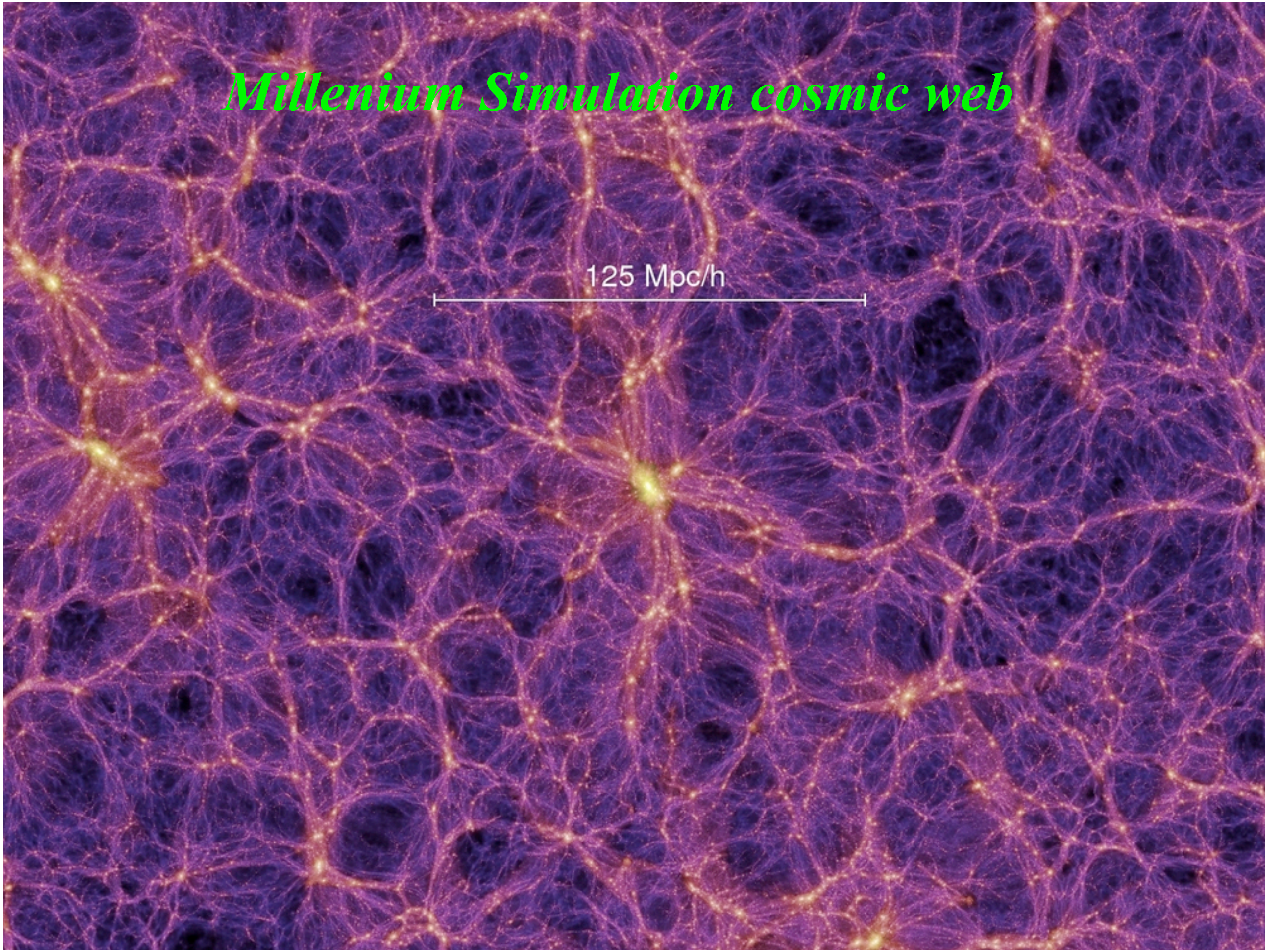
Spiral Galaxy: M31

Dark Matter



Evidence that a massive halo of **Dark Matter** surrounds all galaxies and clusters of galaxies


The Bullet
Cluster


Millenium Simulation cosmic web
125 Mpc/h

Joint Fermilab-LBNL coadd press release

Clearest Picture Yet of Dark Matter Points the Way to Better Understanding of Dark Energy

Scientists at Fermilab and Berkeley Lab build the biggest map of dark matter yet, using methods that will improve ground-based surveys

Independent data reduction and analyses, but coordinated arXiv postings and press release

Fermilab/U. Chicago papers

- ***coadd data: http://arxiv.org/abs/1111.6619, ApJ, submitted***
- ***photometric redshifts: http://arxiv.org/abs/1111.6620, ApJ, in press***
- ***cluster lensing: http://arxiv.org/abs/1111.6621, ApJ, in press***
- ***cosmic shear: http://arxiv.org/abs/1111.6622, ApJ, submitted***

LBNL/UC Berkeley papers

- ***coadd data: http://arxiv.org/abs/1111.6658, MNRAS, submitted***
- ***cosmic shear: http://arxiv.org/abs/1112.3143, MNRAS, submitted***

Collaborators

Fermilab:
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Coadd data paper co-authors:

THE SDSS COADD: 275 DEG^2 OF DEEP SDSS IMAGING ON STRIPE 82

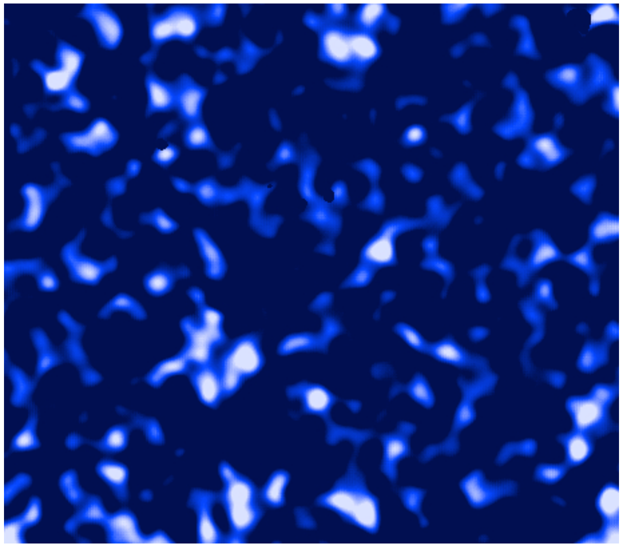
James Annis[1], Marcelle Soares-Santos[1], Robert H. Lupton[2], Michael A. Strauss[2], Andrew C. Becker[3], Scott Dodelson[1,4], Xiaohui Fan[5], James E. Gunn[2], Jiangang Hao [1], Željko Ivezić[3], Sebastian Jester[1,6] Linhua Jiang[5], David E. Johnston[1], Jeffrey M. Kubo[1], Hubert Lampeitl[1,7], Huan Lin[1], Gajus Miknaitis[1], Hee-Jong Seo[8], Melanie Simet[4], Brian Yanny[1]

CFHTLenS press release at AAS

Press Release

Astronomers reach new frontiers of dark matter

You can download a pdf (http://www.roe.ac.uk/~heymans/website_images/AAS2012_press_session_aspdf.pdf) of the AAS Press Conference slides and watch the "through a lens Darkly" (http://www.ustream.tv/recorded/19665280) archive footage of the press conference held 9.30am CST, Jan 9th 2012 in Austin Texas.



The University of British Columbia
The University of Edinburgh
Canada-France-Hawaii Telescope

News Release
Issued: Monday 9 January 2012

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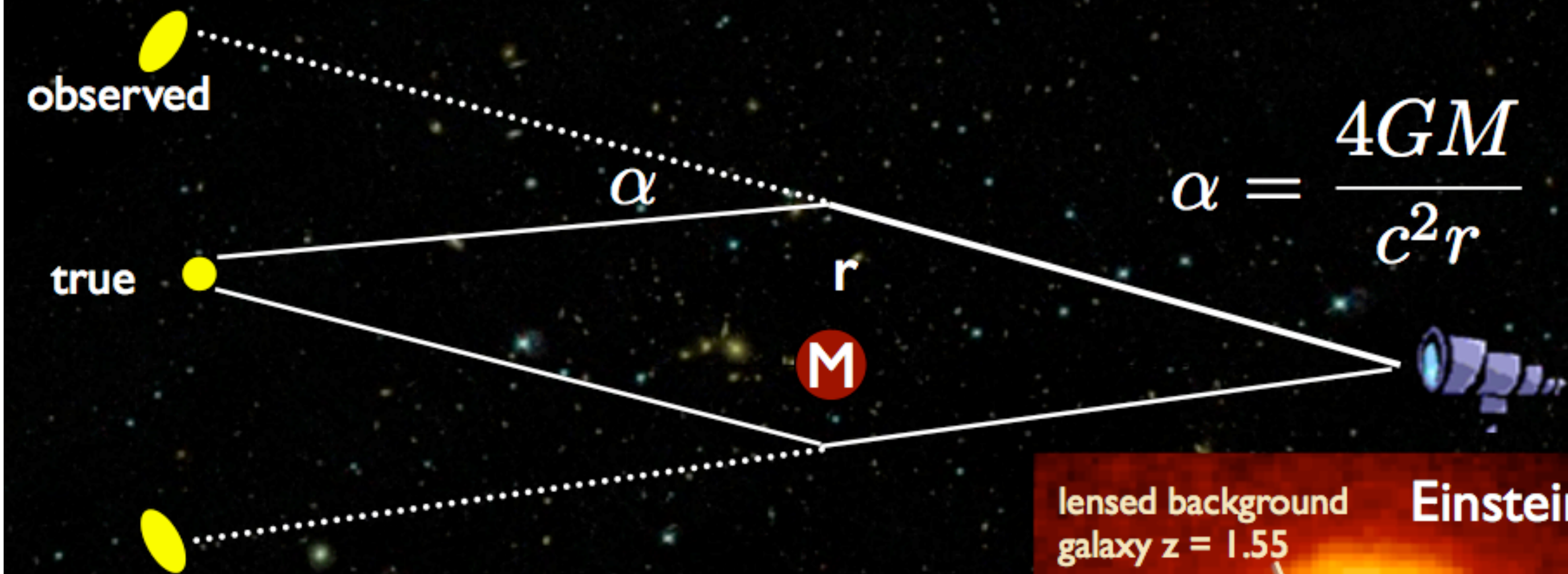
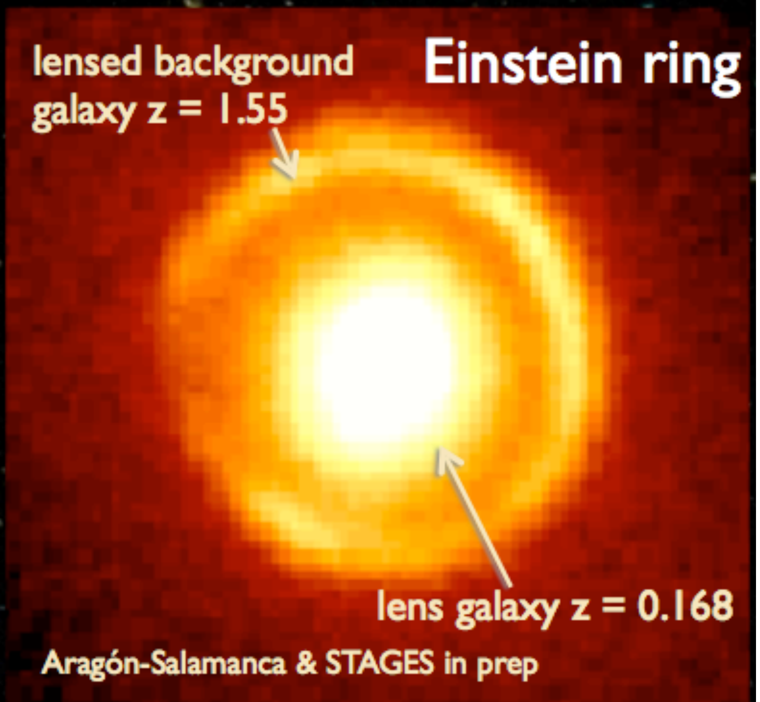
For the first time, astronomers have mapped dark matter on the largest scale ever observed. The results, presented by Dr Catherine Heymans of the University of Edinburgh, Scotland, and Associate Professor Ludovic Van Waerbeke of the University of British Columbia, Vancouver, Canada, are being presented today to the American Astronomical Society meeting in Austin, Texas. Their findings reveal a Universe comprised of an intricate cosmic web of dark matter and galaxies spanning more than one billion light years.

Introduction to gravitational lensing

The Basics of Gravitational Lensing



$$\alpha = \frac{4GM}{c^2 r}$$



- Lensing provides a direct detection and measurement of mass.
- It is the only way that we can observe dark matter on all scales.

Gravitational lens equation

- The angular positions of the lensed images (θ) and the original unlensed source (β) are related through the ***gravitational lens equation***

$$\theta = \beta + \alpha$$

- The lens equation is derived from the geometry of the lensing configuration (see figure)

- ***Cosmology*** enters through the various ***distances*** between source, lens, and observer

- The lensing ***mass distribution*** enters through the (reduced) deflection angle α, which determines how much the light from the source is bent at different (projected) radii from the lens

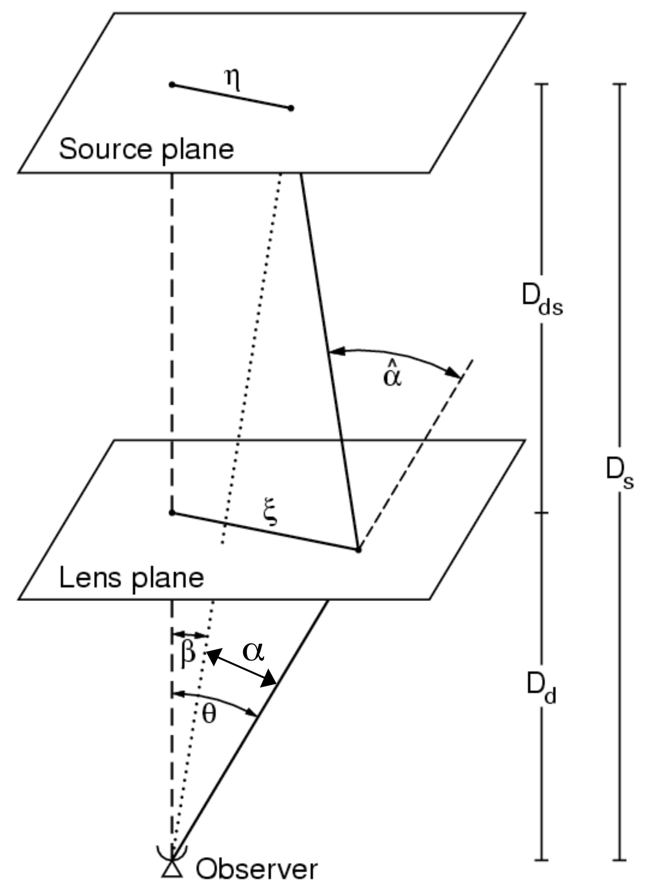


Fig. 12. Sketch of a typical gravitational lens system.

$$A_{ij} = \frac{\delta\beta_i}{\delta\theta_j}$$

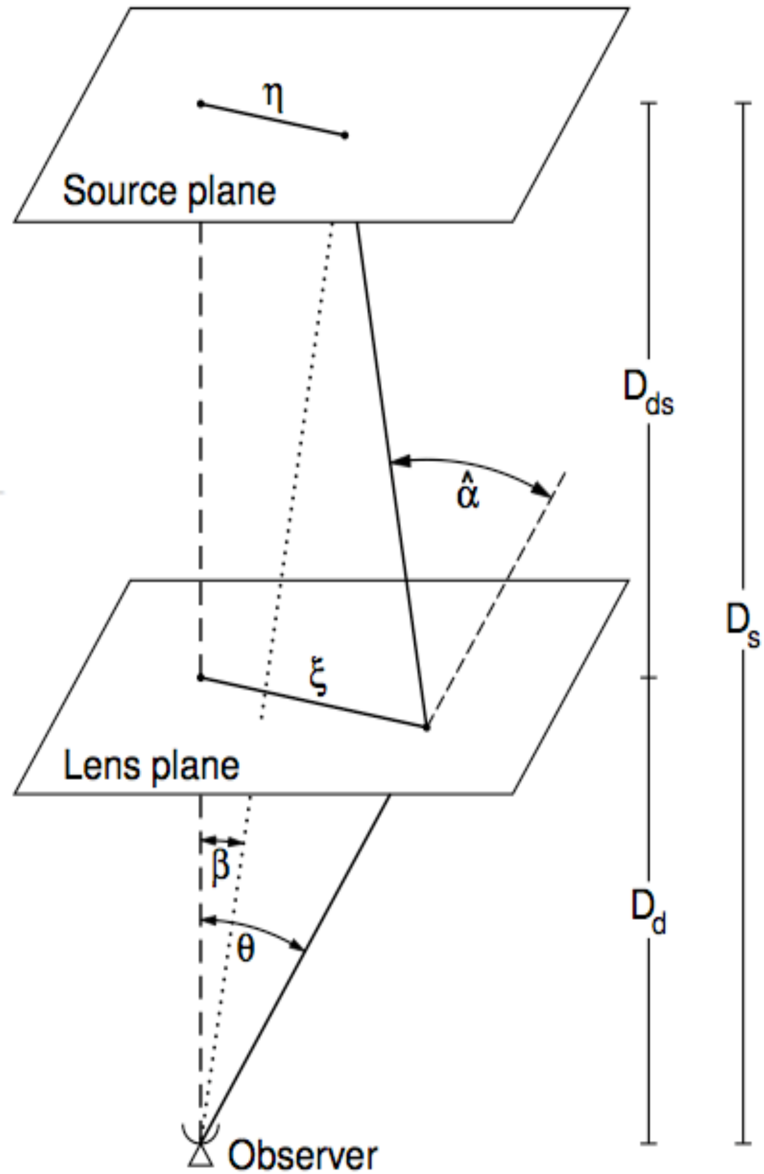
source position

image position

lensing Jacobian matrix

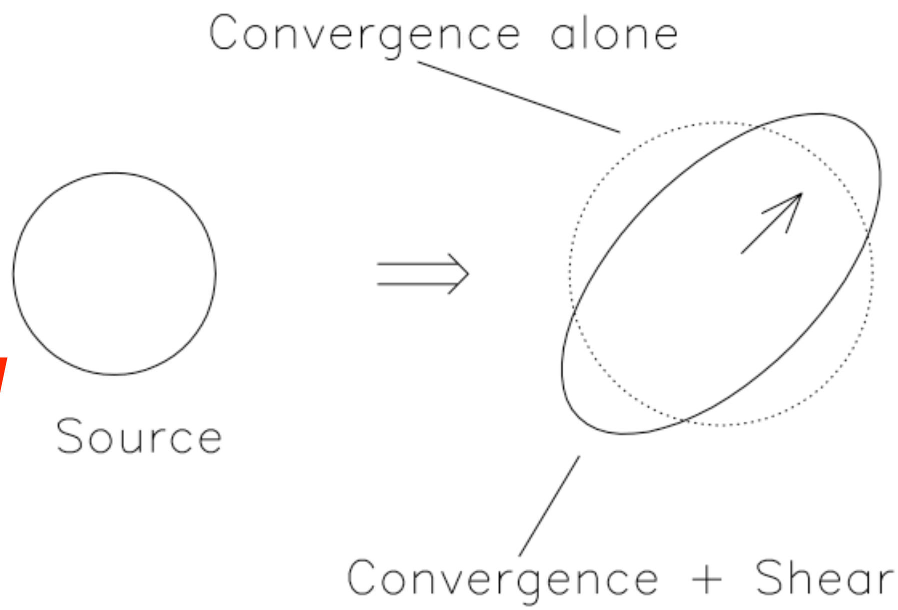
$$A = \begin{pmatrix} 1-\kappa-\gamma_1 & -\gamma_2 \\ -\gamma_2 & 1-\kappa+\gamma_1 \end{pmatrix},$$

- The lensing Jacobian maps the source to the image plane.
- The effect depends on the lensing potential, through the shear and convergence terms
- We want to measure the convergence (mass), but we can only observe the shear.



Convergence and Shear

κ is the "convergence" and (isotropically) changes the size of a lensed galaxy



γ_1 and γ_2 are the 2 components of the "shear" and distort the shape of a lensed galaxy

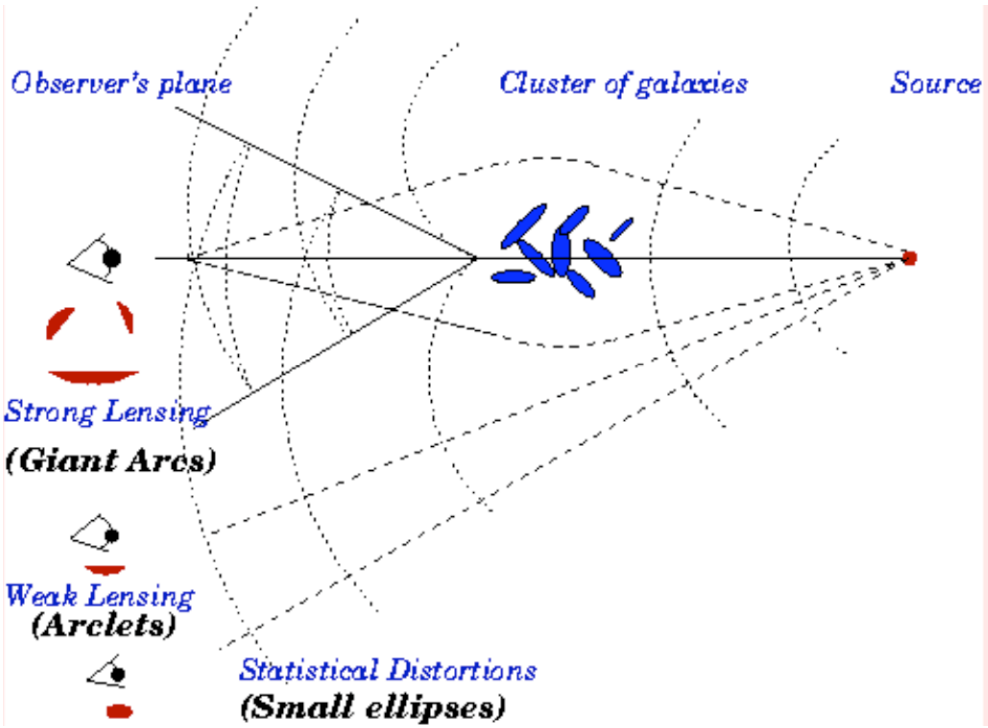
A circle of radius R becomes an ellipse with

$$\text{semi-major axis } a = \frac{R}{1-\kappa-\gamma} \text{ and}$$

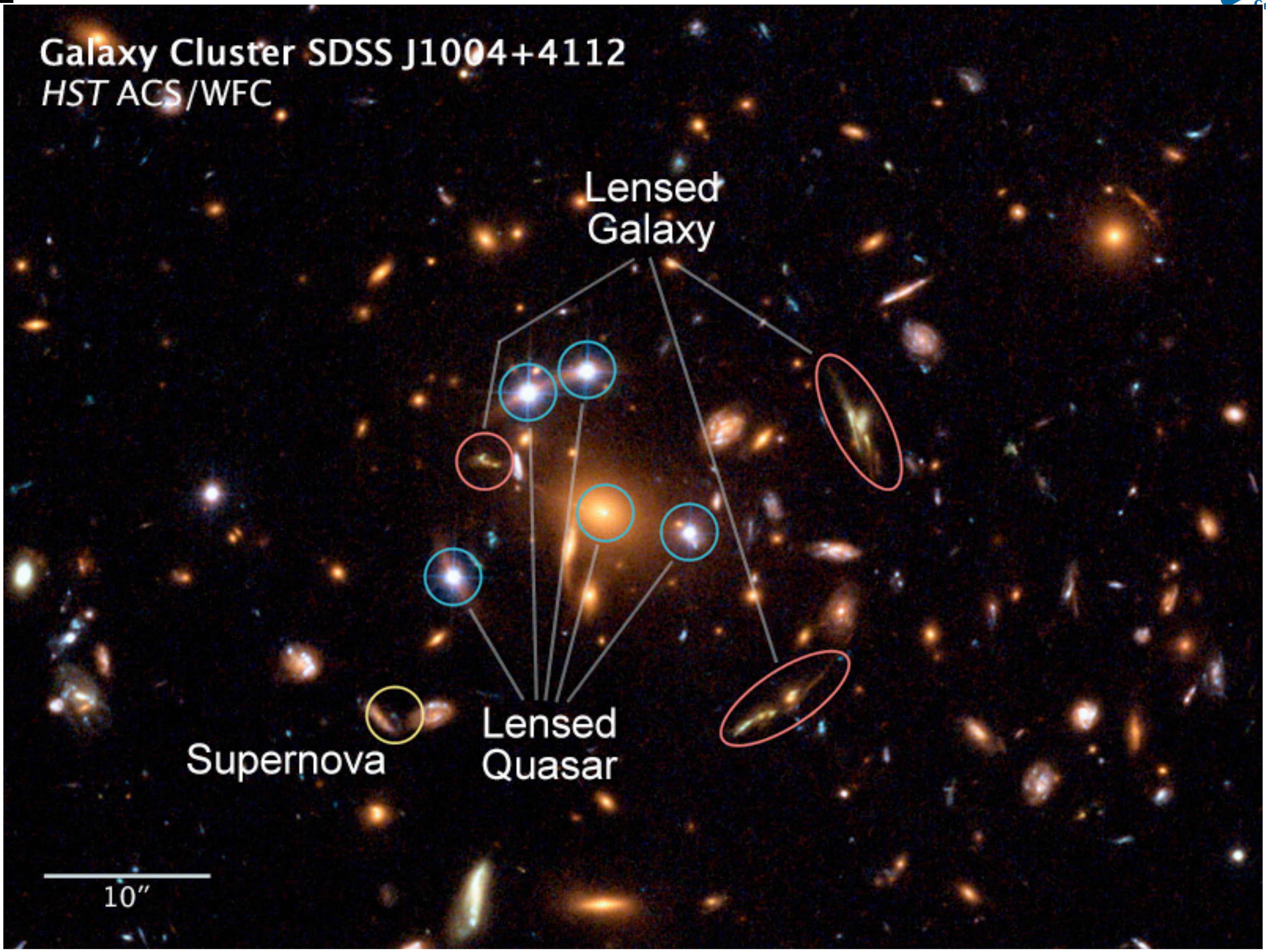
$$\text{semi-minor axis } b = \frac{R}{1-\kappa+\gamma} \text{ where } \gamma = \sqrt{\gamma_1^2+\gamma_2^2}$$

Regimes of lensing

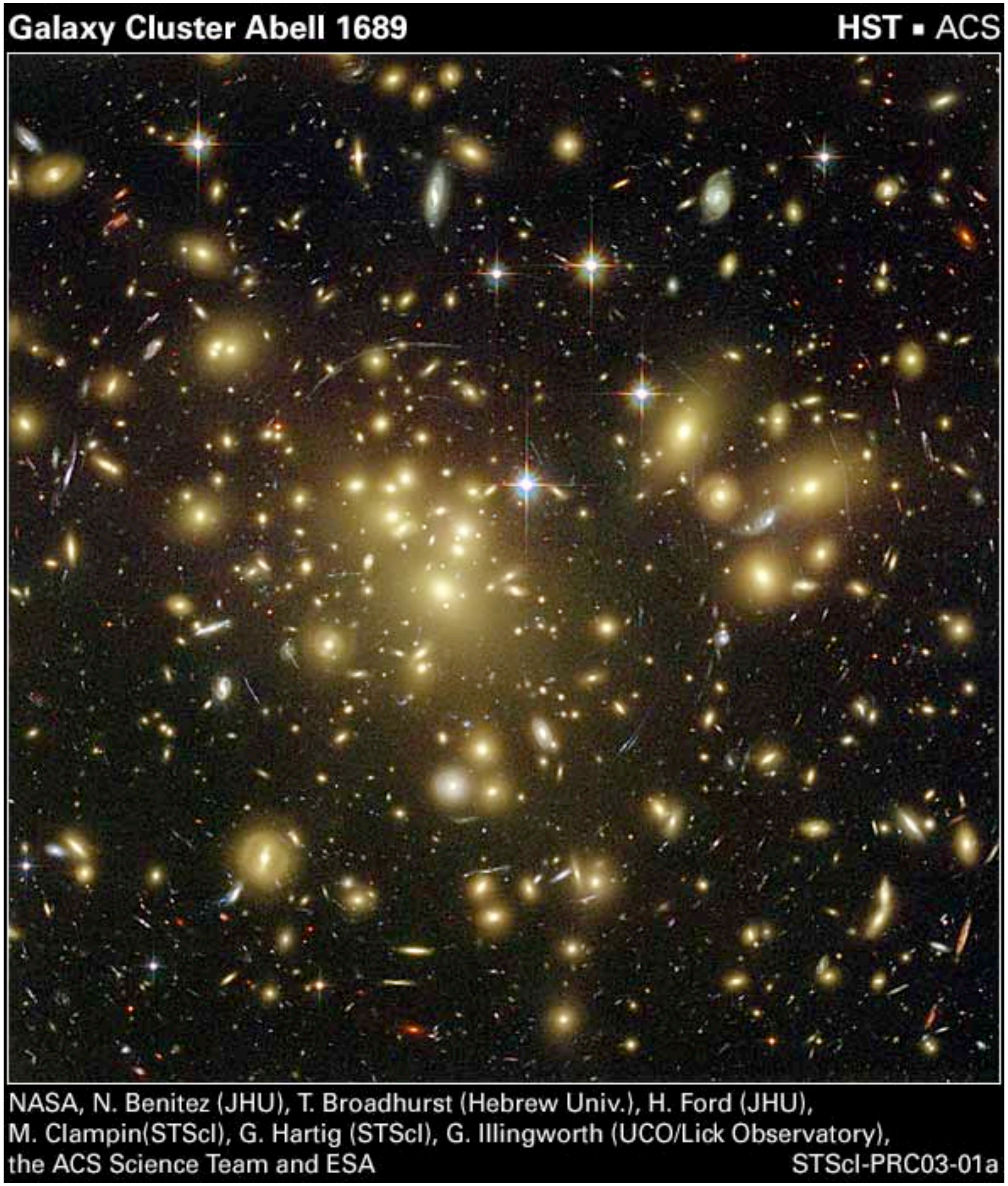
- The distinction between these regimes depends on the relative positions of the source, lens, and observer, and on the mass distribution of the lens
- ***Strong lensing*** produces multiple images, arcs, and Einstein rings
- ***Weak lensing*** produces small distortions ($\kappa, \gamma << 1$) at the level of a few percent in the shapes of distant galaxies



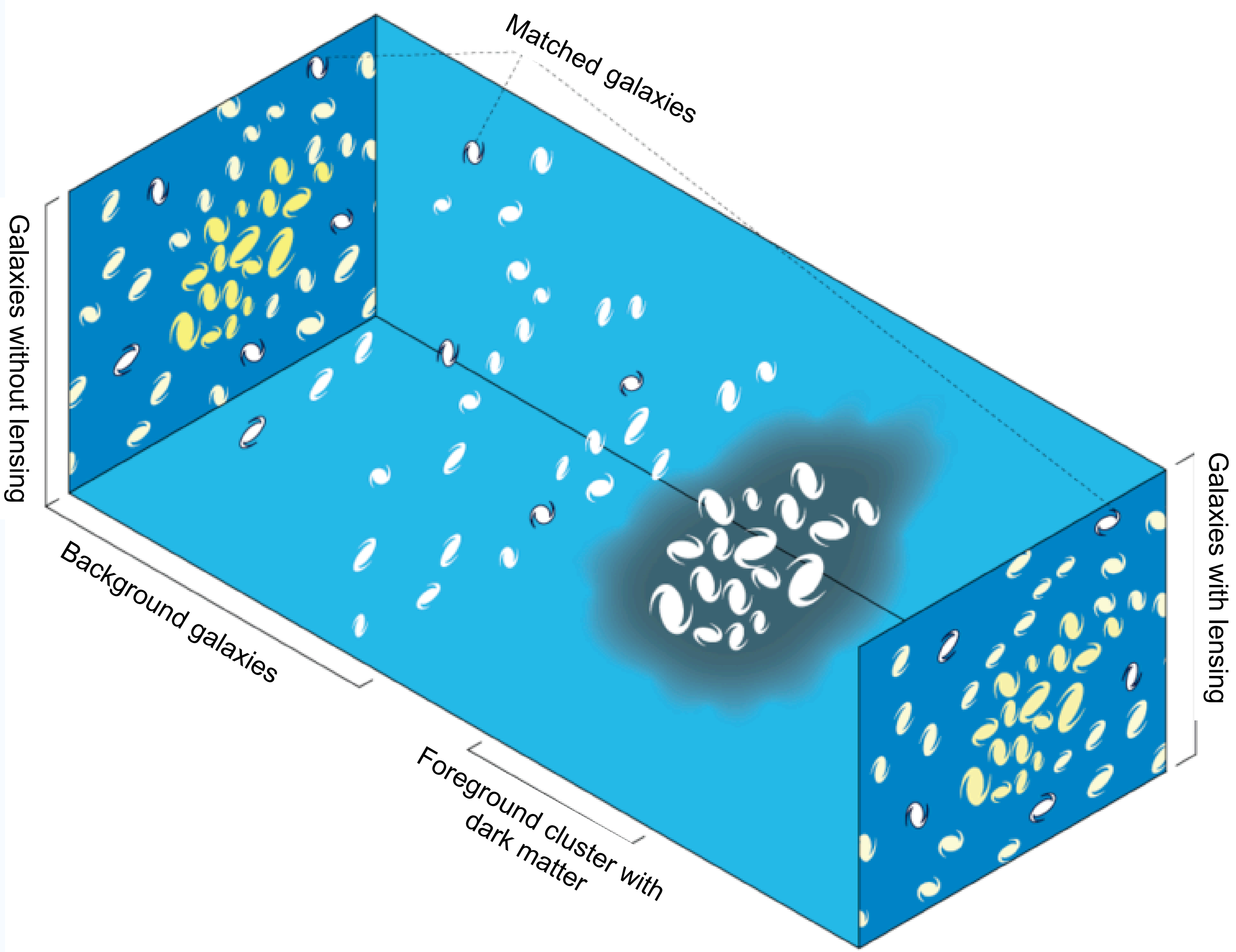
Strong lensing example: multiple images



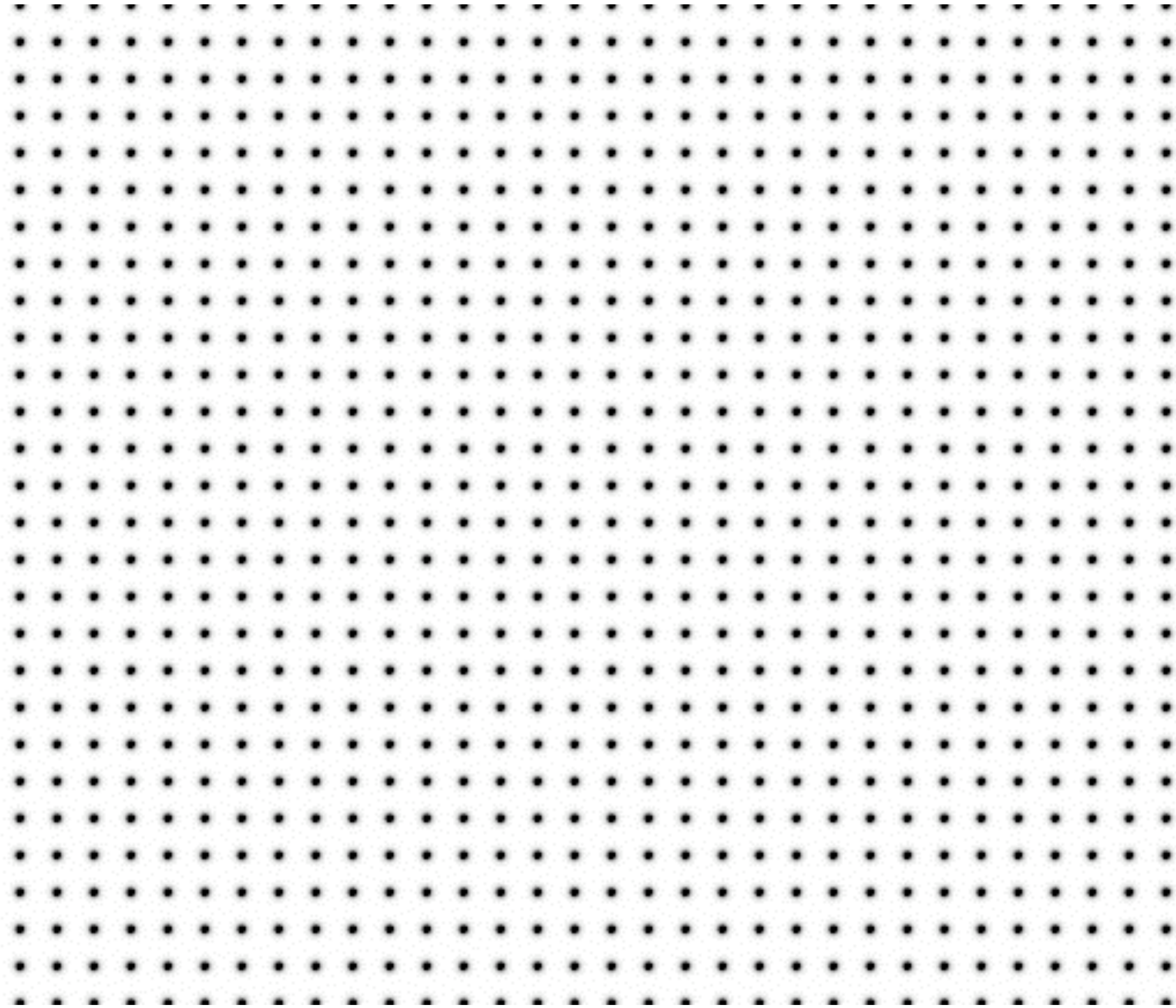
Strong lensing example: giant arcs



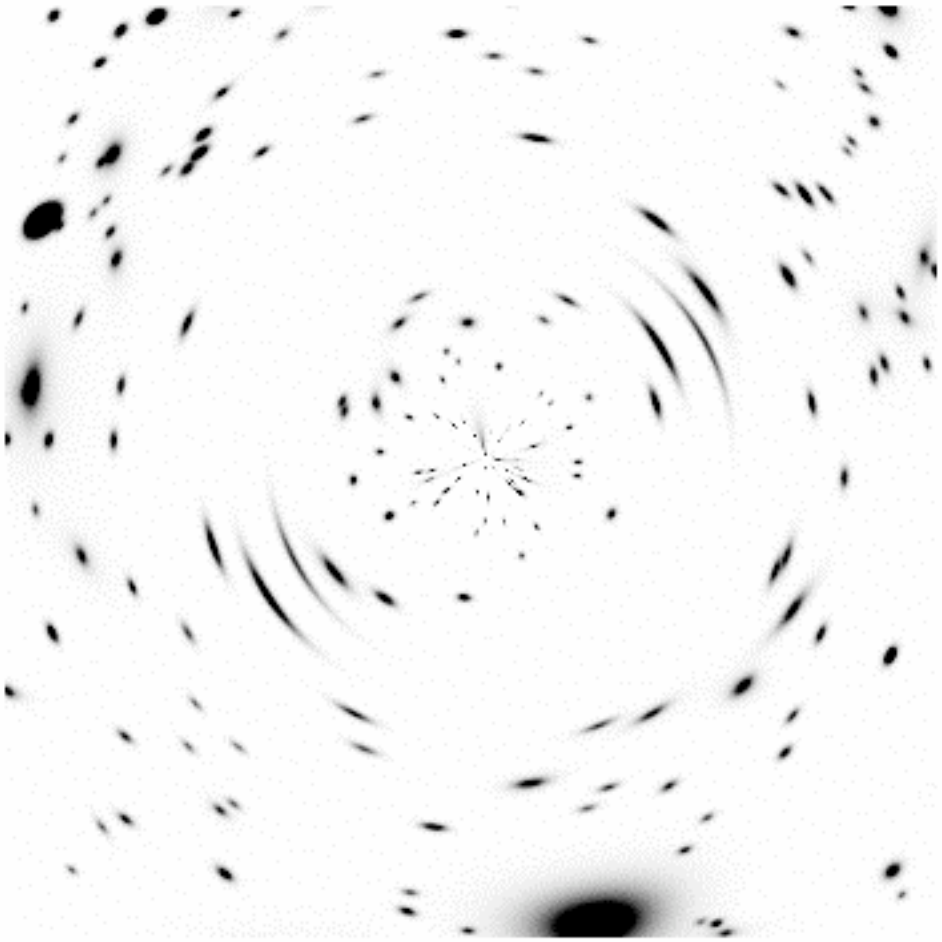
Weak lensing example: background galaxies lensed by foreground cluster

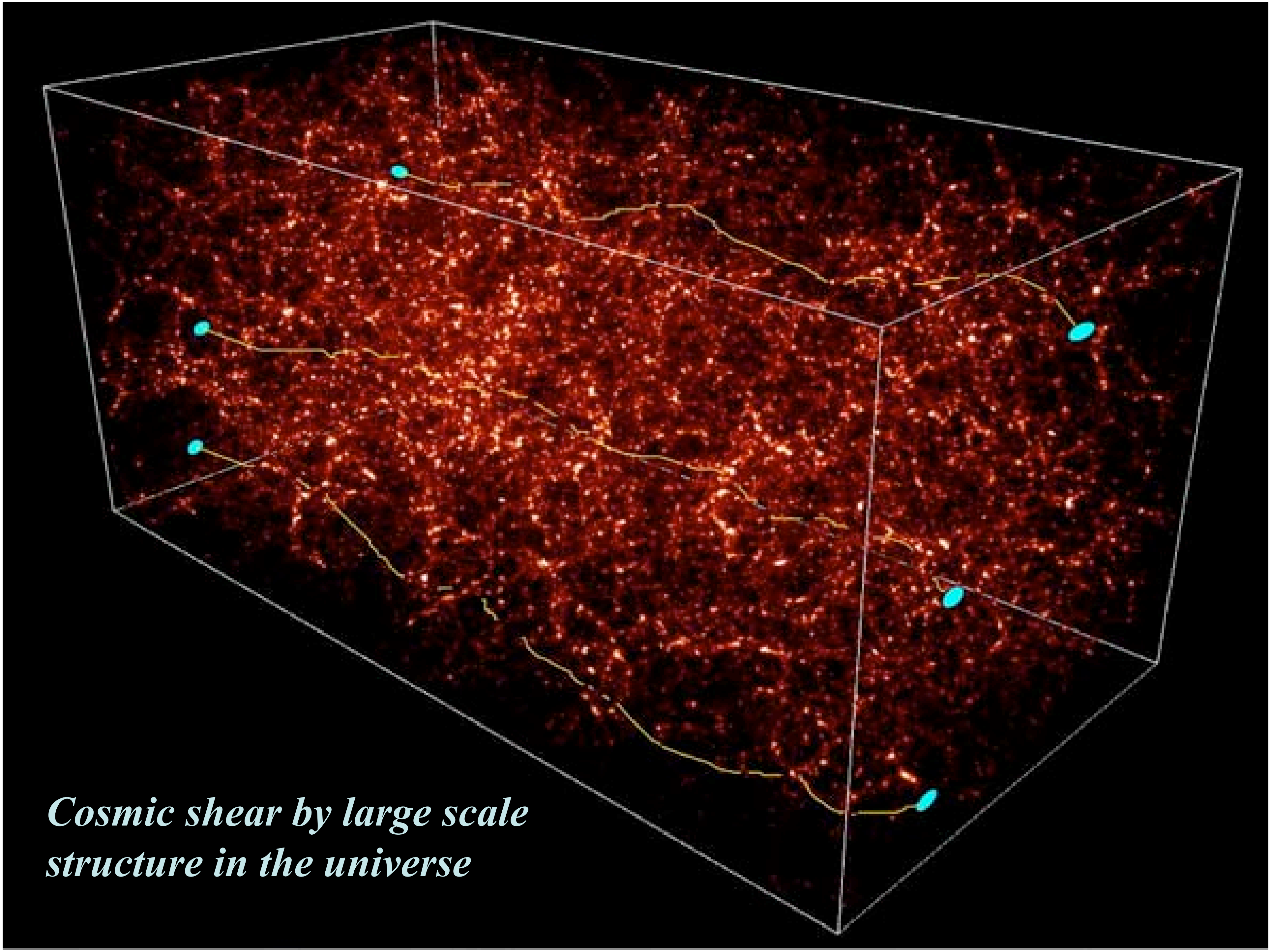


(dark) Cluster lensing a grid of round background galaxies

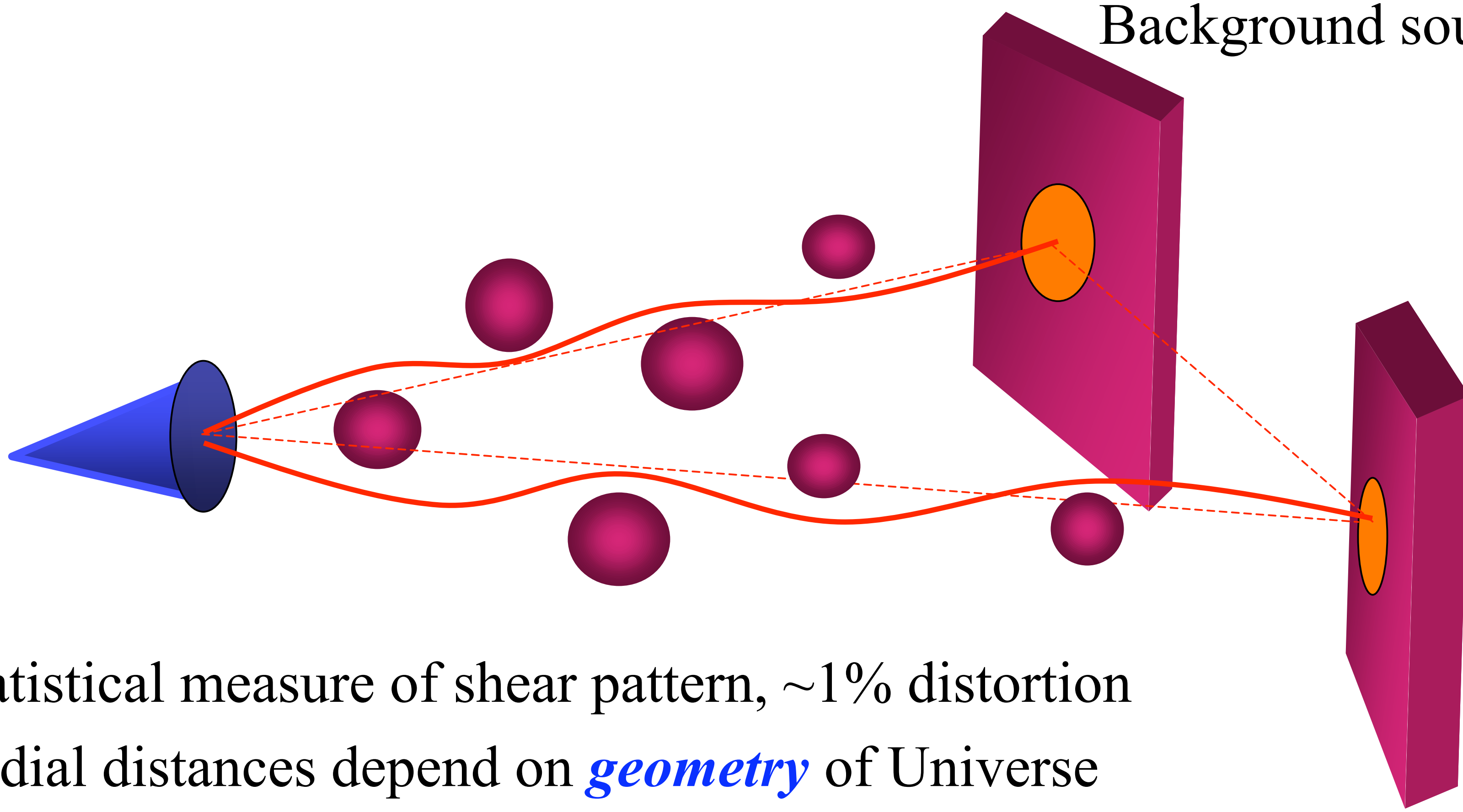


(dark) Cluster lensing a set of realistic background galaxies




Cosmic shear by large scale
structure in the universe

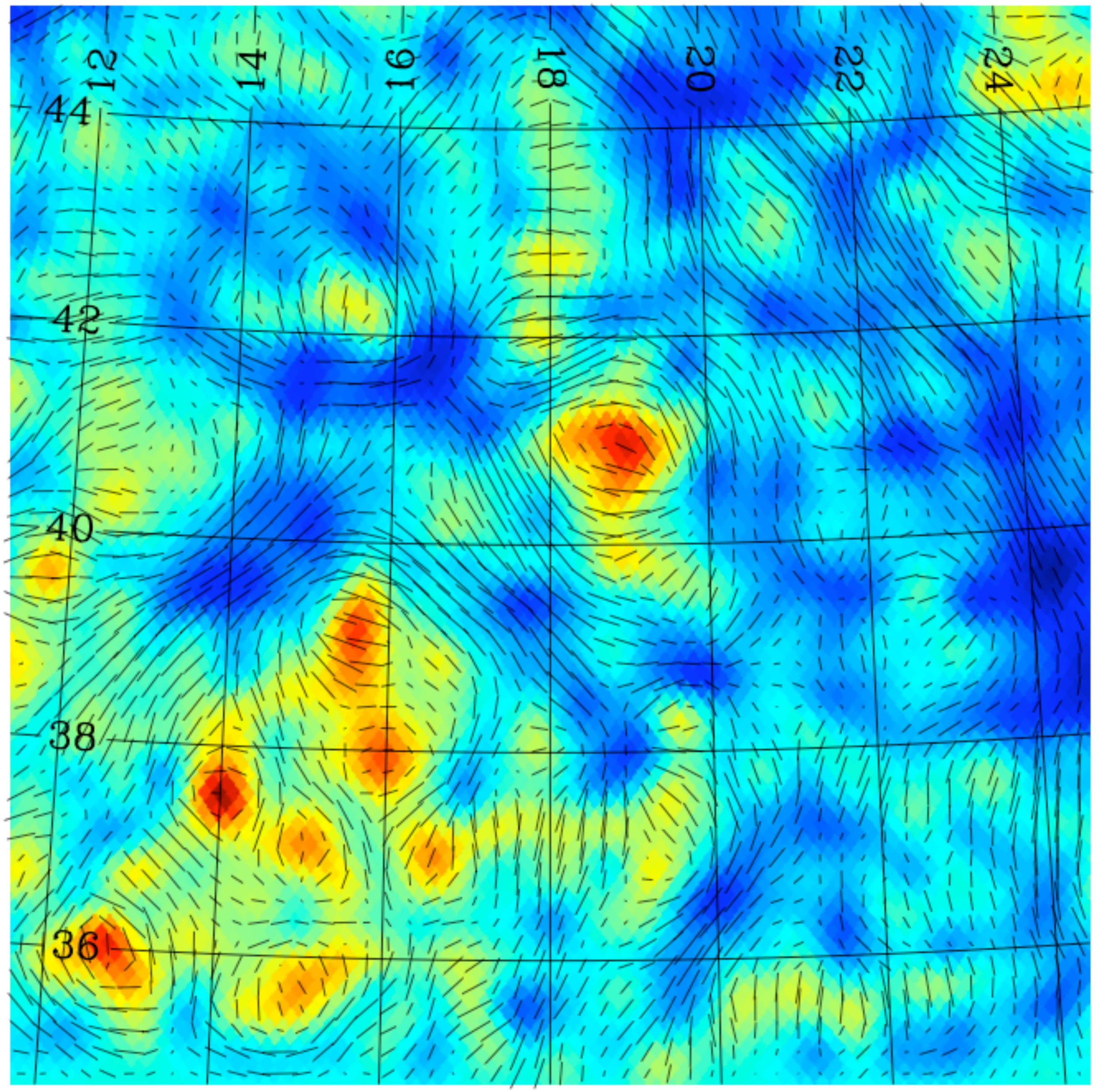
Weak lensing cosmic shear



- Statistical measure of shear pattern, ~1% distortion
- Radial distances depend on ***geometry*** of Universe
- Foreground mass distribution depends on ***growth*** of structure

Slide from J. Frieman

Map of DES “DC6B” 200 deg^2 simulated convergence and shear fields



Colors indicates convergence ∝ surface mass density

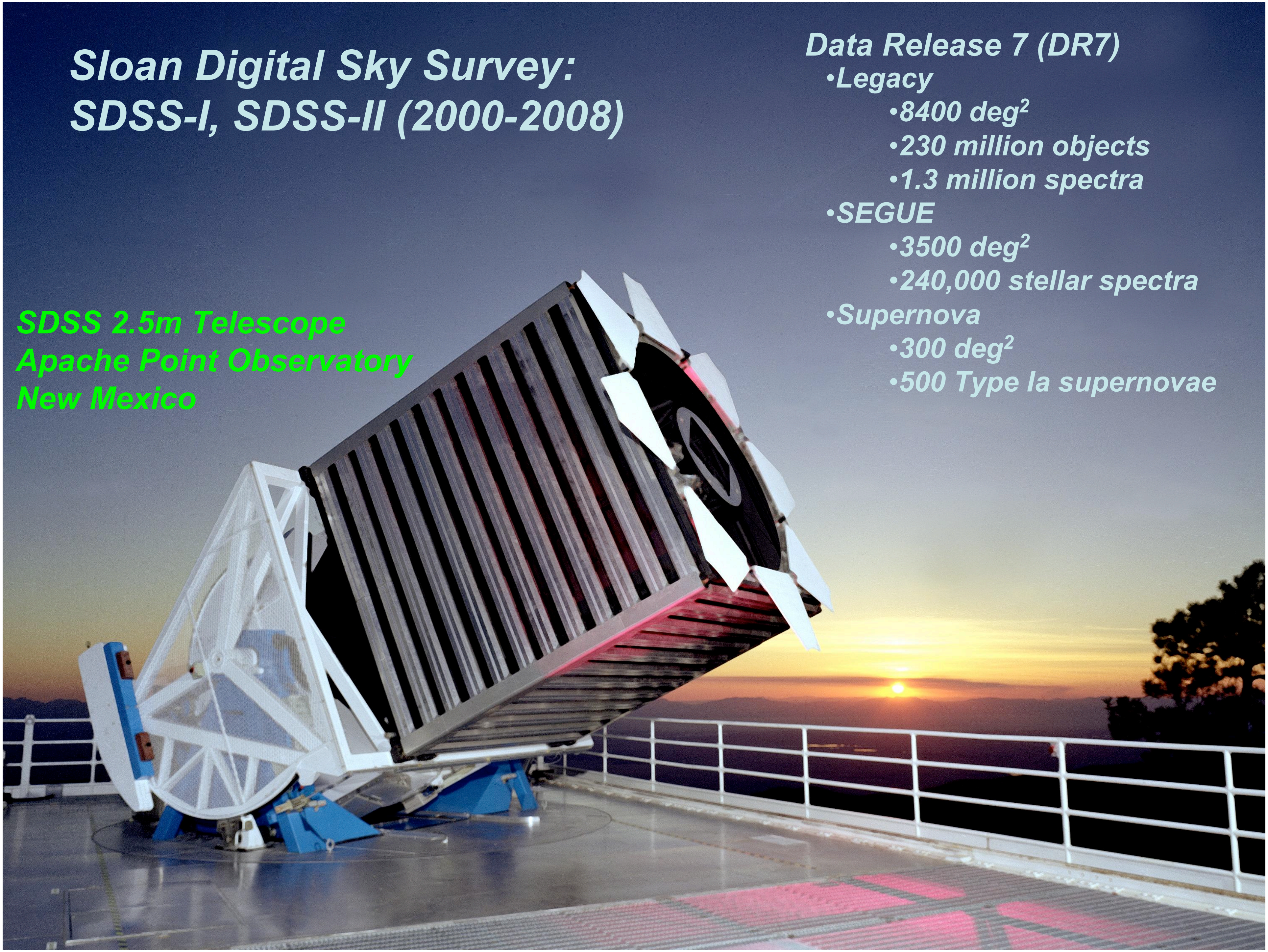
red ==> high density
blue ==> low density

Black “whiskers” show lensing shear field

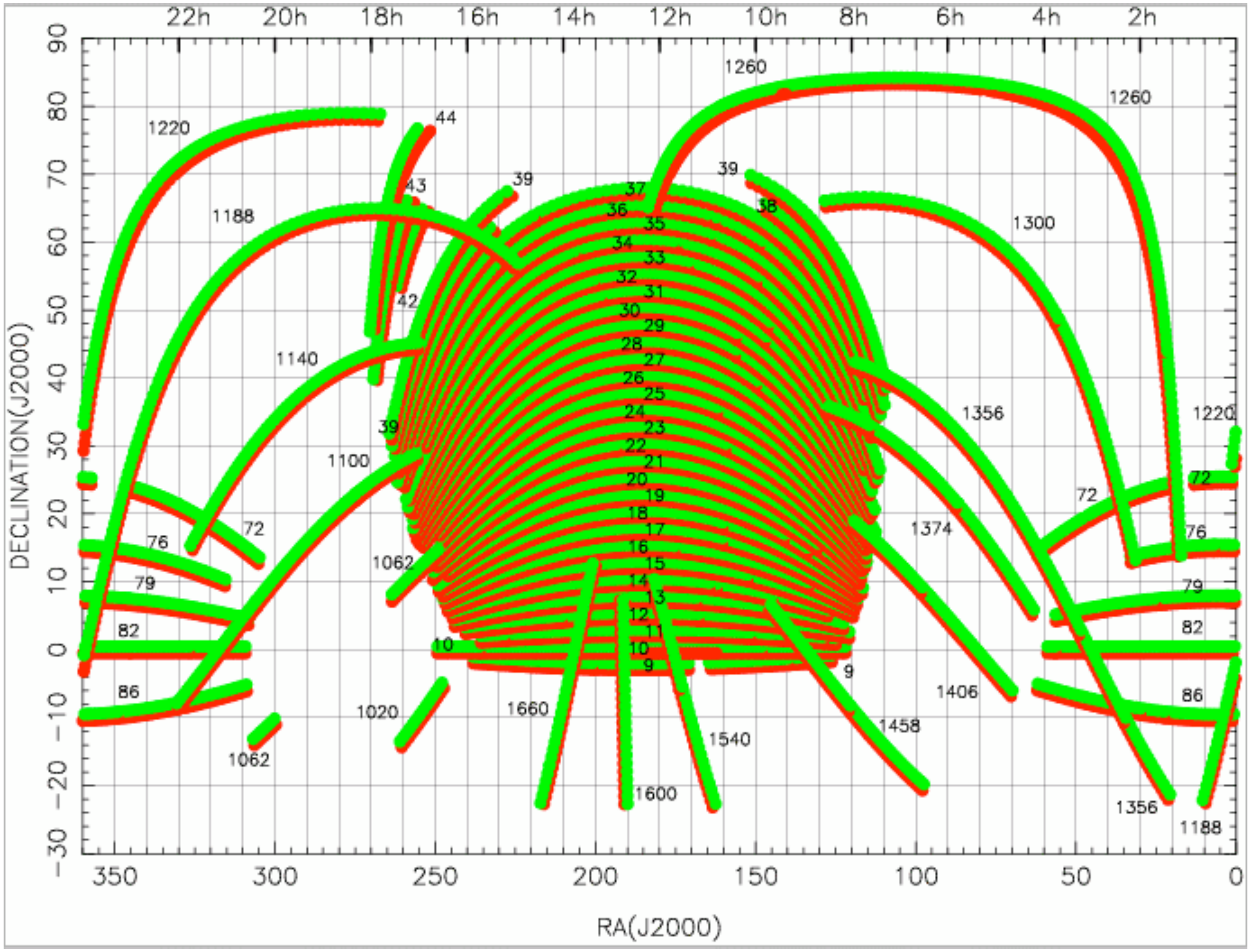
Whiskers indicate magnitude and direction of lensing distortions acting on galaxy shapes

Figure from M. Becker

The SDSS coadd


Sloan Digital Sky Survey:
SDSS-I, SDSS-II (2000-2008)
Data Release 7 (DR7)
•Legacy
•8400 deg^2
•230 million objects
•1.3 million spectra
•SEGUE
•3500 deg^2
•240,000 stellar spectra
•Supernova
•300 deg^2
•500 Type Ia supernovae
SDSS 2.5m Telescope
Apache Point Observatory
New Mexico

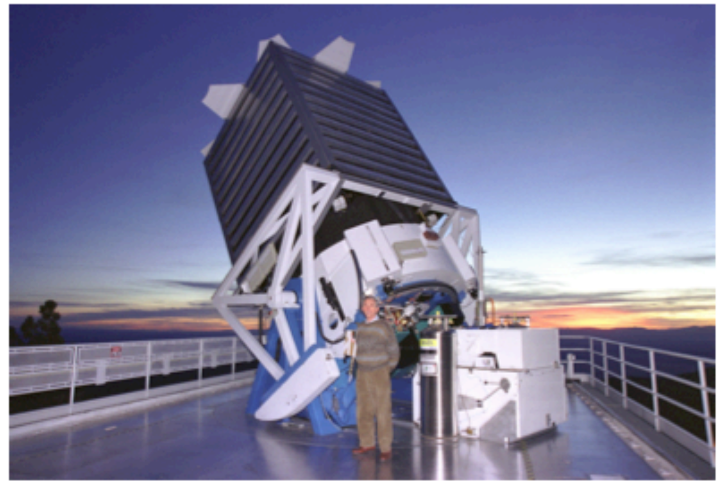
SDSS DR7 footprint

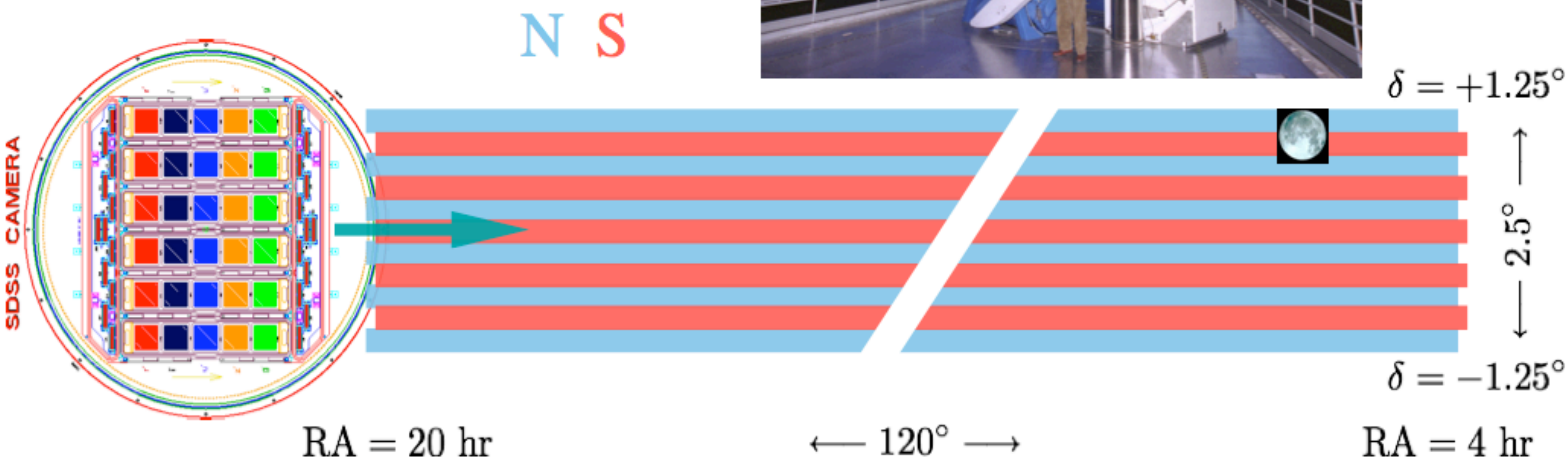


Stripe 82, on celestial equator

SDSS-II SN Survey

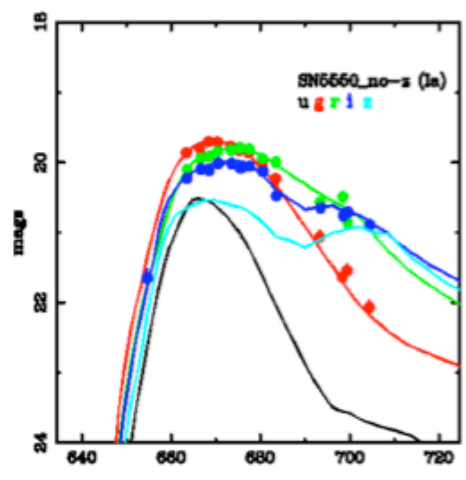
Frieman, et al (2008); Sako, et al (2008)





Use the SDSS 2.5m telescope

- September 1 - November 30 of 2005-2007
- Scan 300 square degrees every 2 days
- Obtain densely sampled multi-color light curves
- Results today from 2005 season



Kessler, et al 09; Lampeitl et al 09; Sollerman et al 09

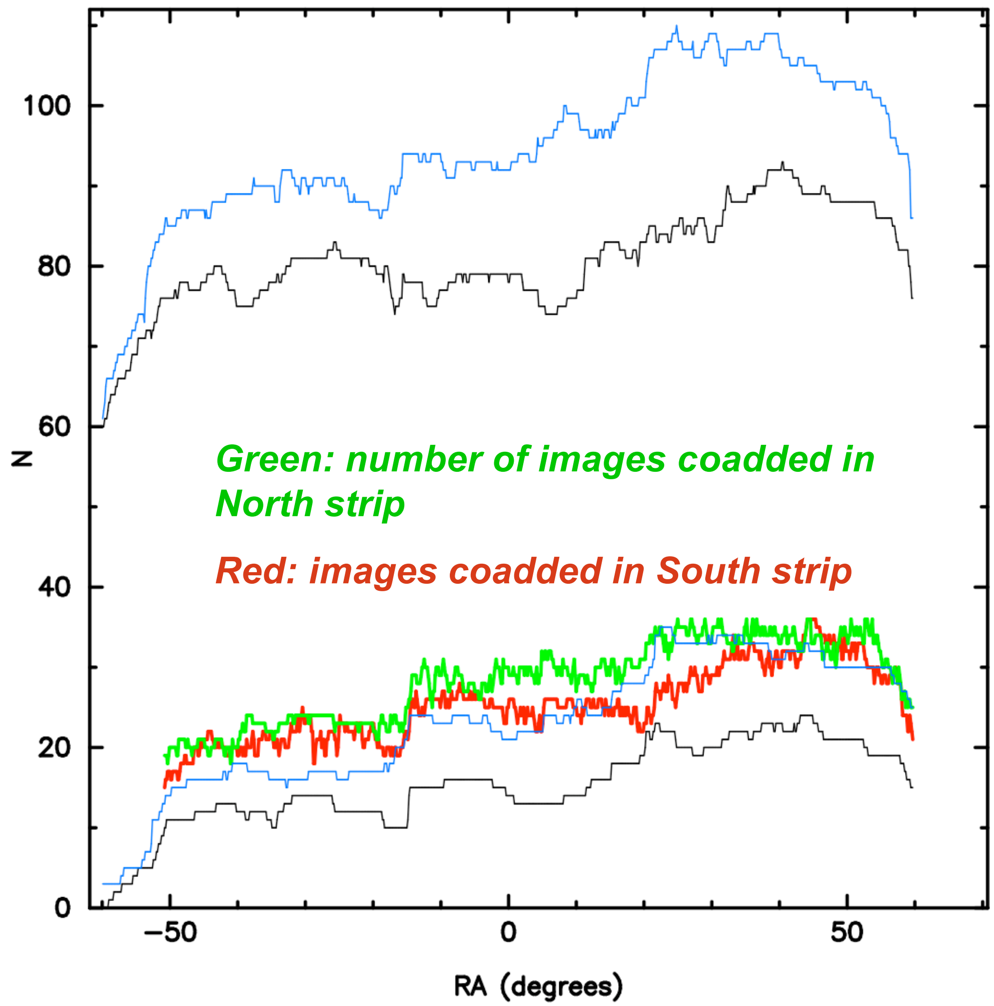
Slide from J. Frieman

SDSS coadd data: Annis et al. (2011), arXiv:1111.6619

- 110 deg x 2.5 deg = 275 deg^2 area
- Used 123 runs taken on or before 1 Dec 2005
- 15-34 single-epoch images coadded, depending on location along Stripe 82
- Input images selected based on *r*-band
  - Image quality (seeing FWHM < 2'')
  - Sky brightness (fainter than 19.5 mag/$arcsec^2$)
  - Photometric extinction (< 0.2 mag)

- Input images re-mapped to a common grid of output images
- Image coaddition done by averaging, with inverse variance weighting according to the image quality (seeing FWHM) and sky brightness of the individual input images
  - Optimal for imaging depth

- Images and catalogs publicly available as part of SDSS DR7



Single-epoch vs. coadd images

(randomly?) selected single-epoch field

Single-epoch vs. coadd images

(randomly?) selected single-epoch field *Coadd of 28 single-epoch runs*

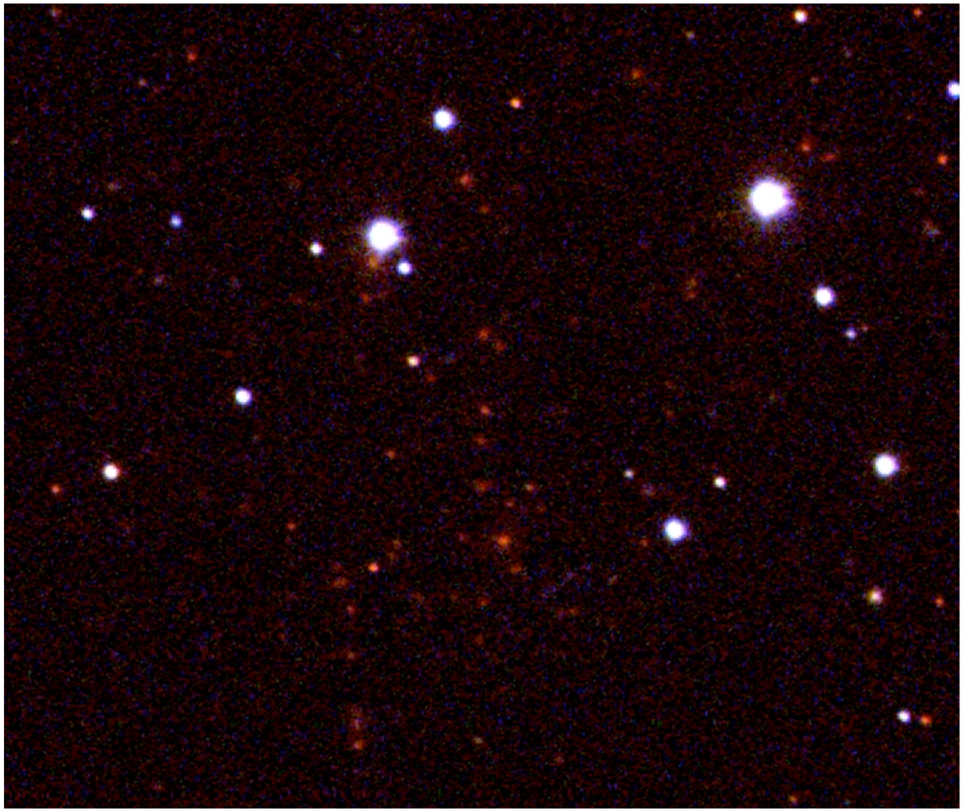
Single epoch vs. coadd images

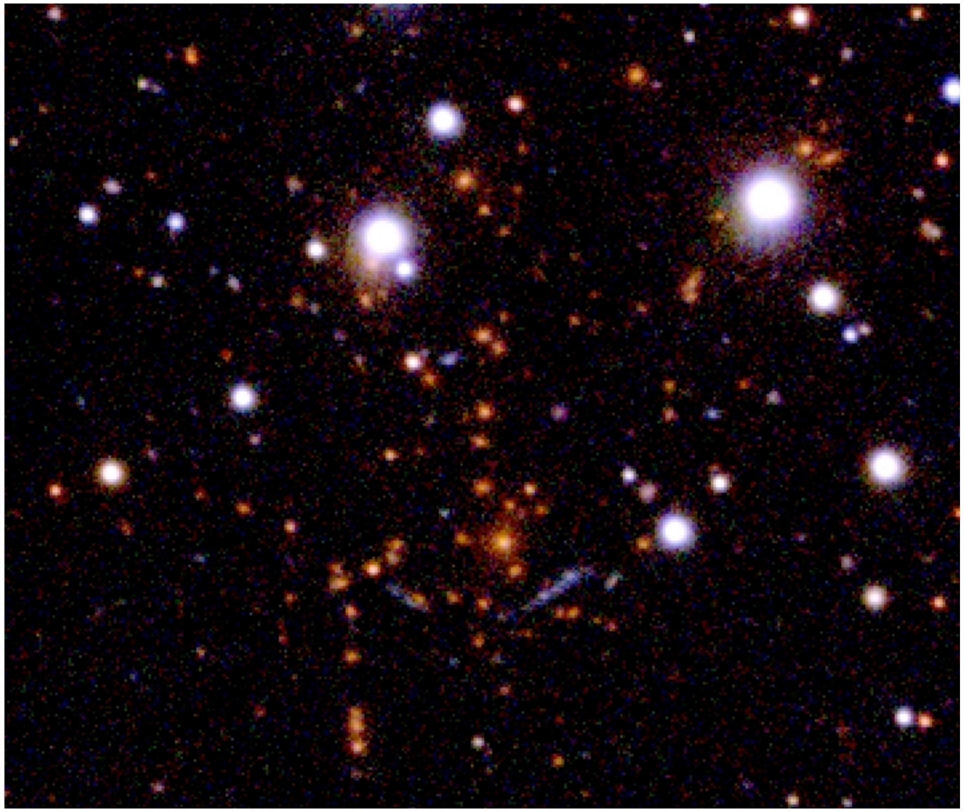
(not randomly) selected single-epoch field

Can see a cluster of reddish galaxies?

Single epoch vs. coadd images

(not randomly) selected
single-epoch field



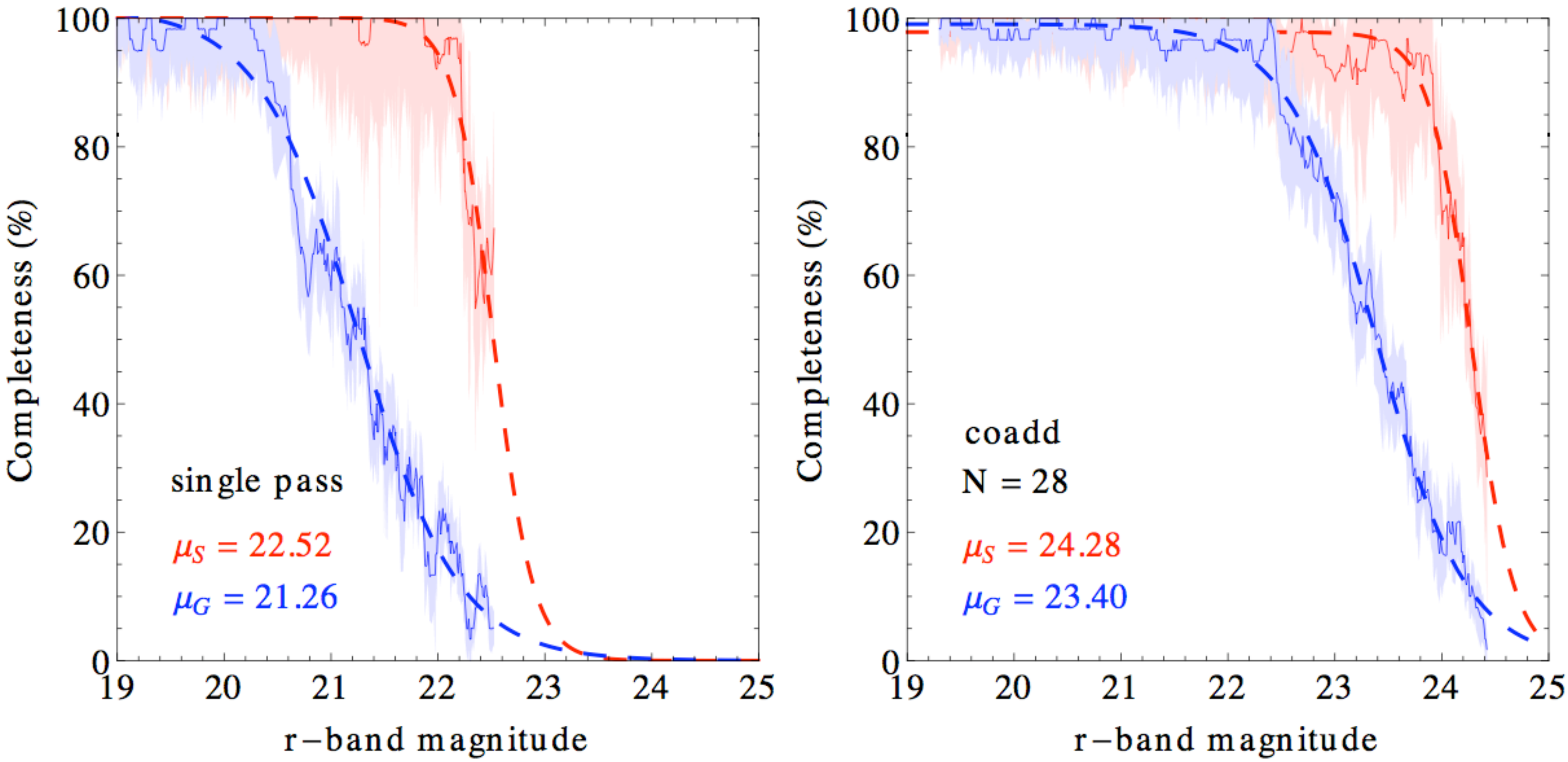


Can see a cluster of reddish galaxies

Coadd: now see rich cluster
and giant arcs!

Completeness for stars and galaxies

Coadd is deeper than single pass by about 2 magnitudes, or a factor of about 6 in flux



Coadd cosmic shear analysis

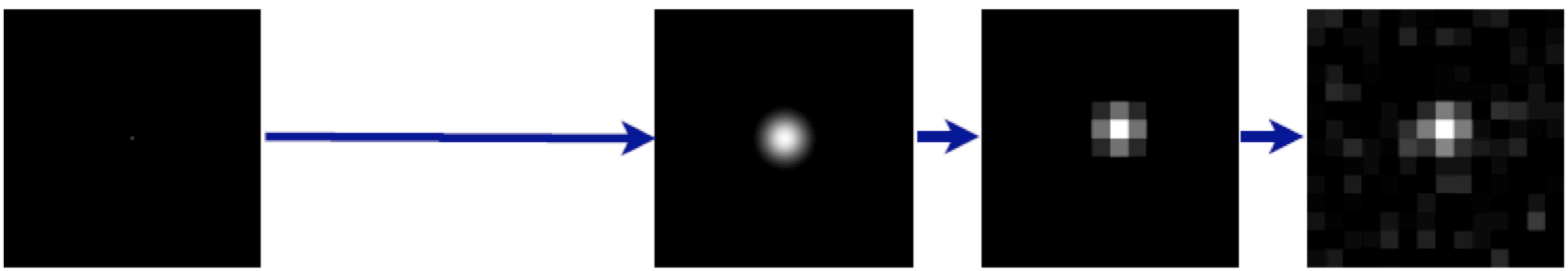
From Galaxy and Star to CCD

The Forward Process.

Galaxies: Intrinsic galaxy shapes to measured image:

Intrinsic galaxy (shape unknown) | Gravitational lensing causes a ***shear (g)*** | Atmosphere and telescope cause a convolution | Detectors measure a pixelated image | Image also contains noise

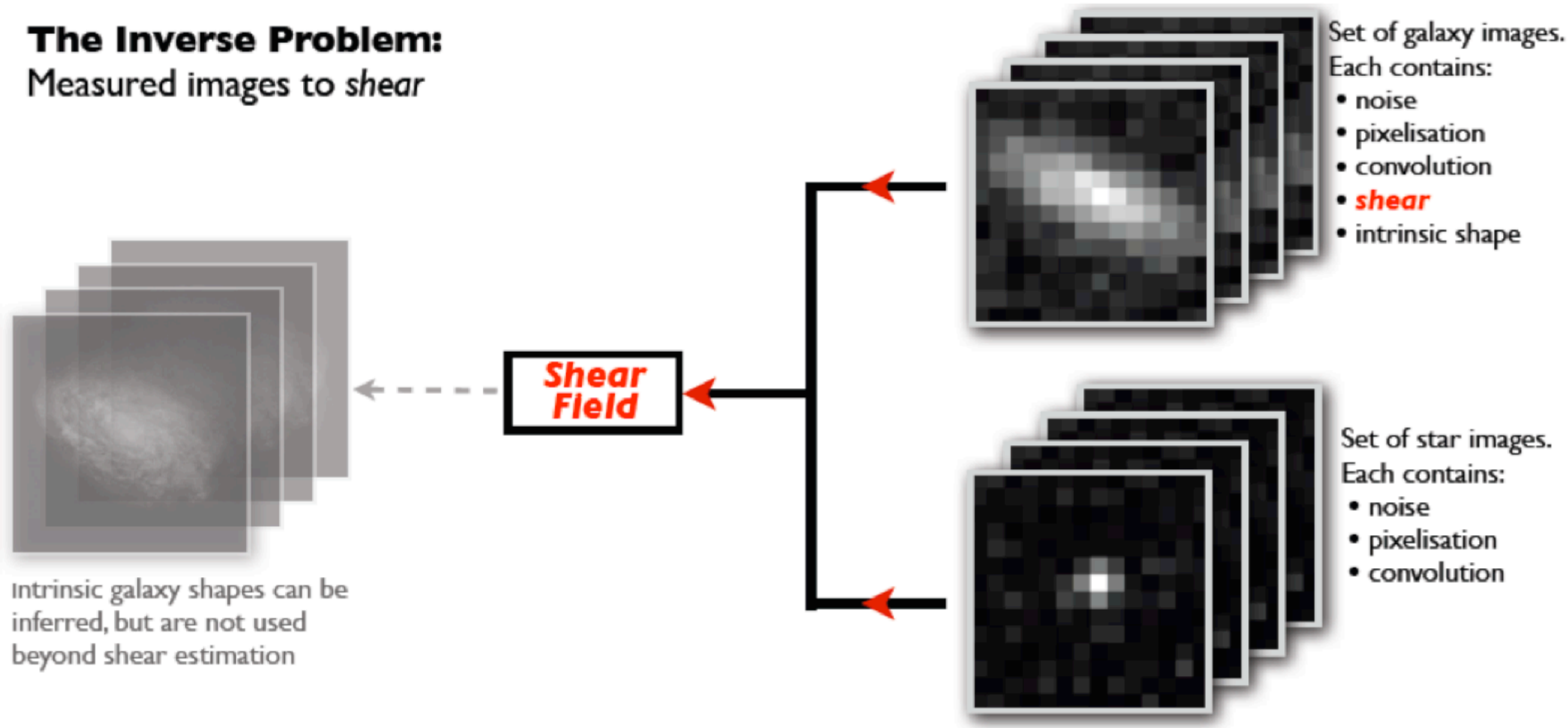
Stars: Point sources to star images:



Intrinsic star (point source) | Atmosphere and telescope cause a convolution | Detectors measure a pixelated image | Image also contains noise

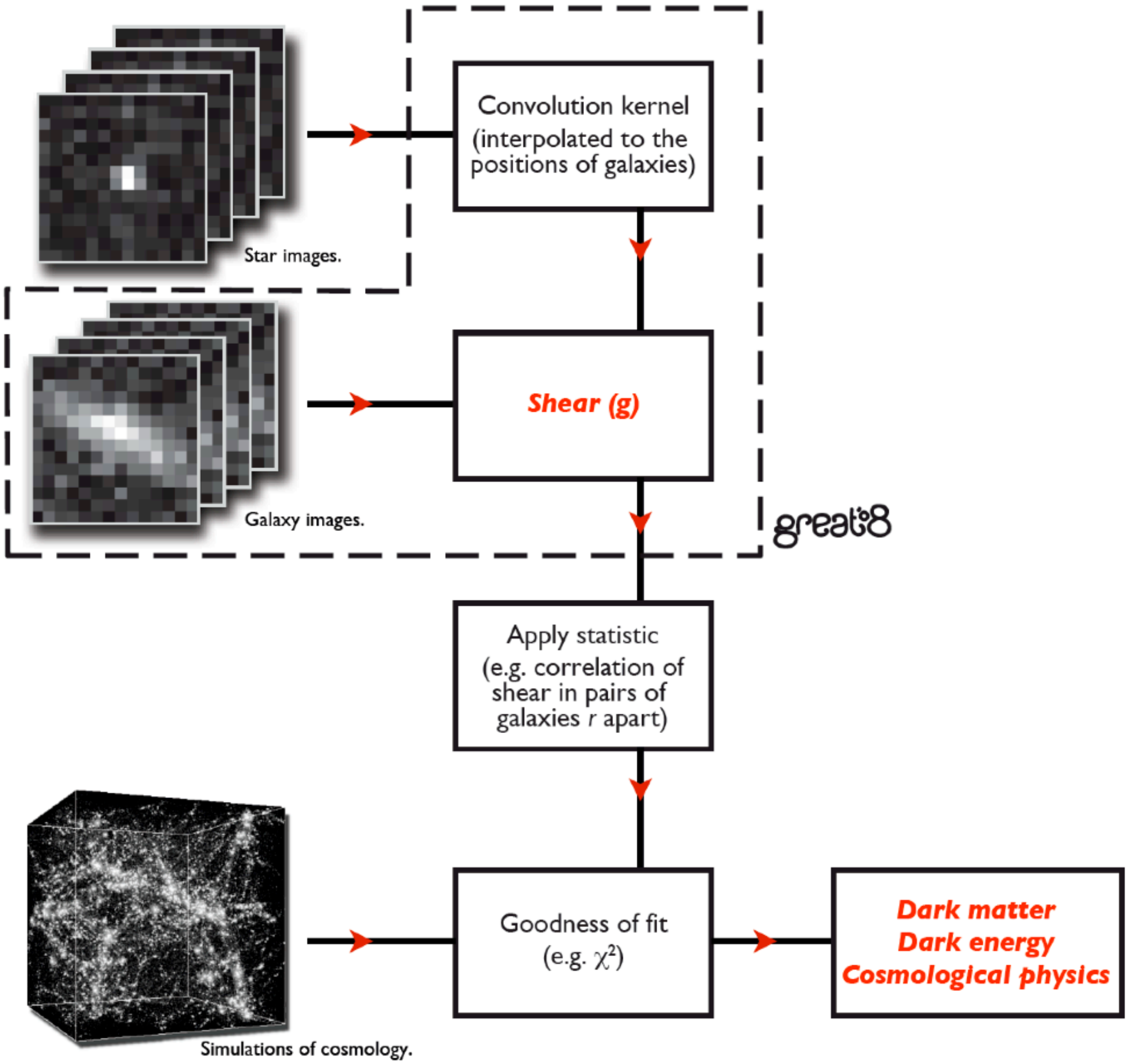
Weak lensing analyses reverse this process

The Inverse Problem:
Measured images to *shear*



From weak lensing catalogue to DM and DE

A full weak lensing pipeline:
The broader context typical for cosmological measurements

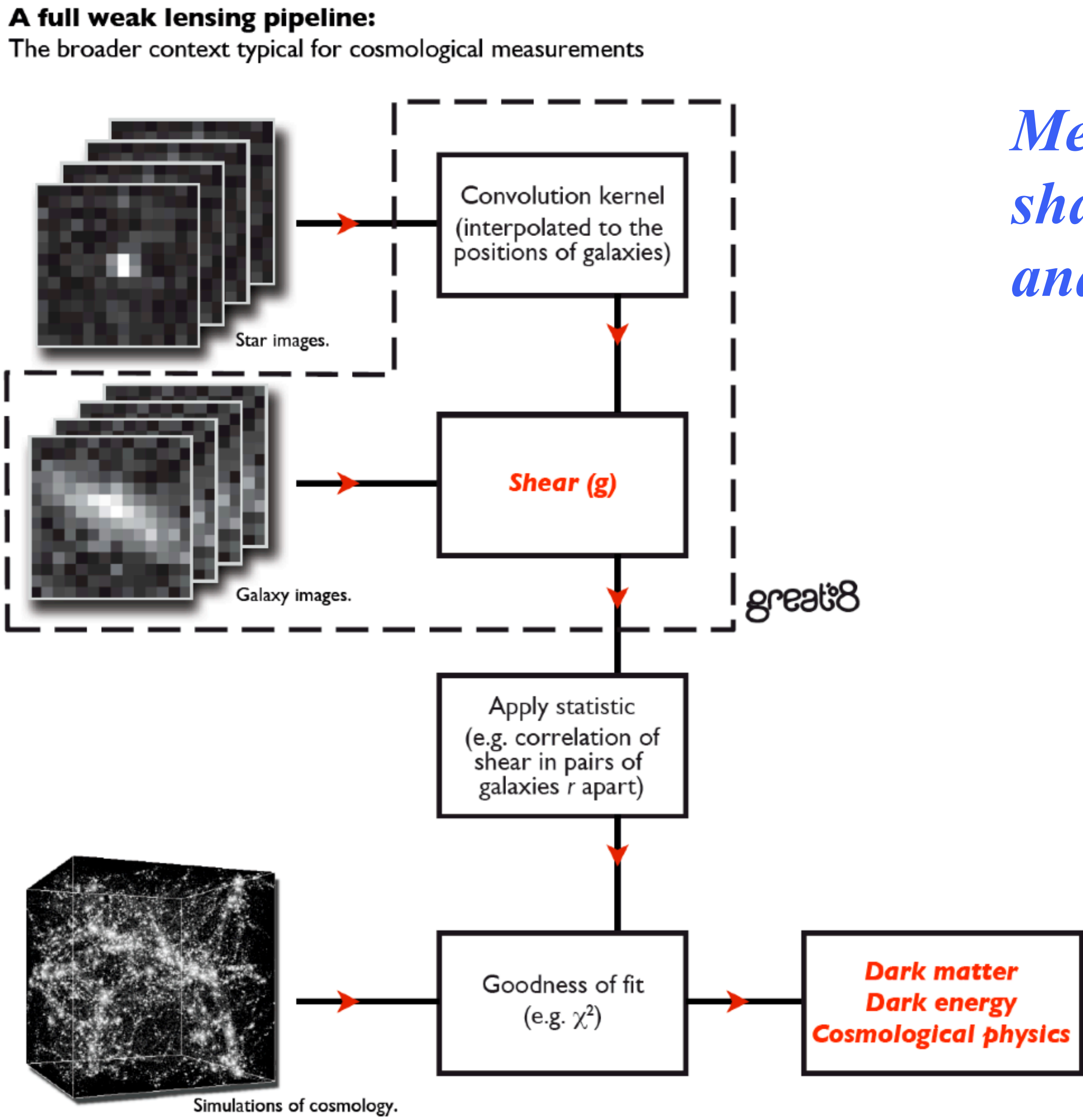


Coadd cosmic shear pipeline
Lin et al. (2011), arXiv:1111.6622

Center for Particle Astrophysics

- SDSS “Photo” photometry pipeline
  - Object detection, photometry (brightness of objects), and classification (star/galaxy separation)
  - Size and shape measurements using “adaptive moments”
- Correct galaxy sizes and shapes (ellipticities/shears) for PSF effects using “linear PSF correction” algorithm of Hirata & Seljak (2003)
- Photometric redshifts computed from *ugriz* photometry using artificial neural network method (Reis et al. 2011; Oyaizu et al. 2008a,b)
- Select galaxies for analysis based on various cuts (later slide)
- Compute galaxy ellipticities averaged over square pixels (0.1 deg on a side) covering coadd area
- Compute shear-shear correlation functions and power spectra from binned ellipticities
- Carry out cosmology fit

From weak lensing catalogue to DM and DE



Measure sizes and shapes of galaxies and stars

From Galaxy and Star to CCD

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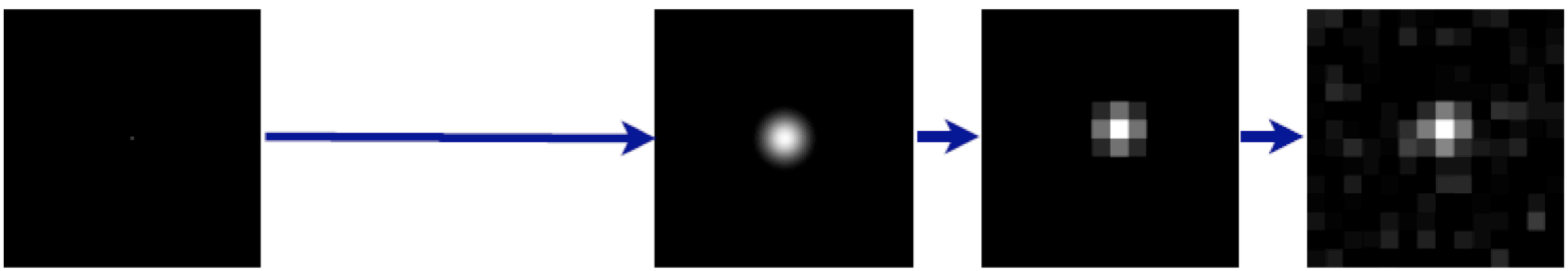


Intrinsic star (point source) | Atmosphere and telescope cause a convolution | Detectors measure a pixelated image | Image also contains noise

Centroids and Quadrupole Moments

- Lensing changes the shapes of galaxies, so we need a statistic with which to quantify their shape.
- The first moment determines an objects centroid

$$
\begin{aligned}
\bar{x} &= \int I(x,y)\, x \, \mathrm{d}x \, \mathrm{d}y \\
\bar{y} &= \int I(x,y)\, y \, \mathrm{d}x \, \mathrm{d}y \ ,
\end{aligned}
$$

- The second moment (or quadrupole moments determines shape)

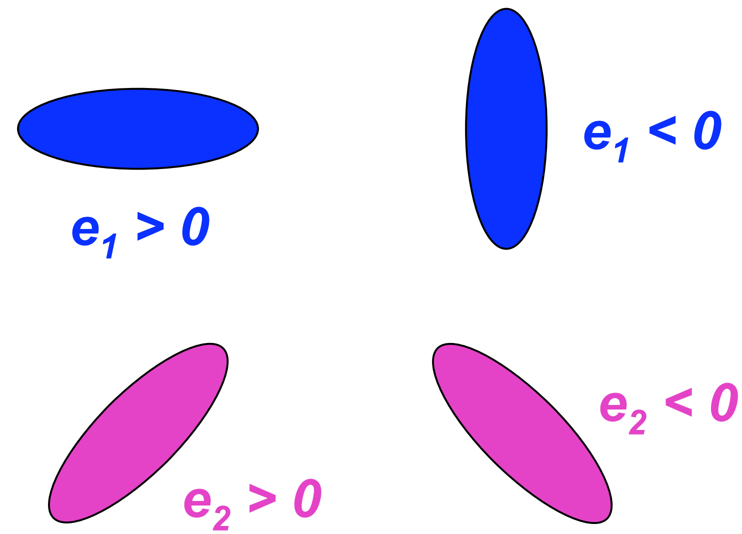
$$
\begin{aligned}
Q_{xx} &= \int I(x,y)\,(x-\bar{x})^2 \, \mathrm{d}x \, \mathrm{d}y \\
Q_{xy} &= \int I(x,y)\,(x-\bar{x})(y-\bar{y}) \, \mathrm{d}x \, \mathrm{d}y \\
Q_{yy} &= \int I(x,y)\,(y-\bar{y})^2 \, \mathrm{d}x \, \mathrm{d}y.
\end{aligned}
$$

Weak lensing ellipticity definition

(my favorite version)

$$e_1 = \frac{Q_{xx} - Q_{yy}}{Q_{xx} + Q_{yy}}$$

$$e_2 = \frac{2Q_{xy}}{Q_{xx} + Q_{yy}}$$



For weak lensing (κ and $\gamma << 1$), we have

$$e_1 \approx 2\gamma_1$$

$$e_2 \approx 2\gamma_2$$

Observables : Galaxy Ellipticity

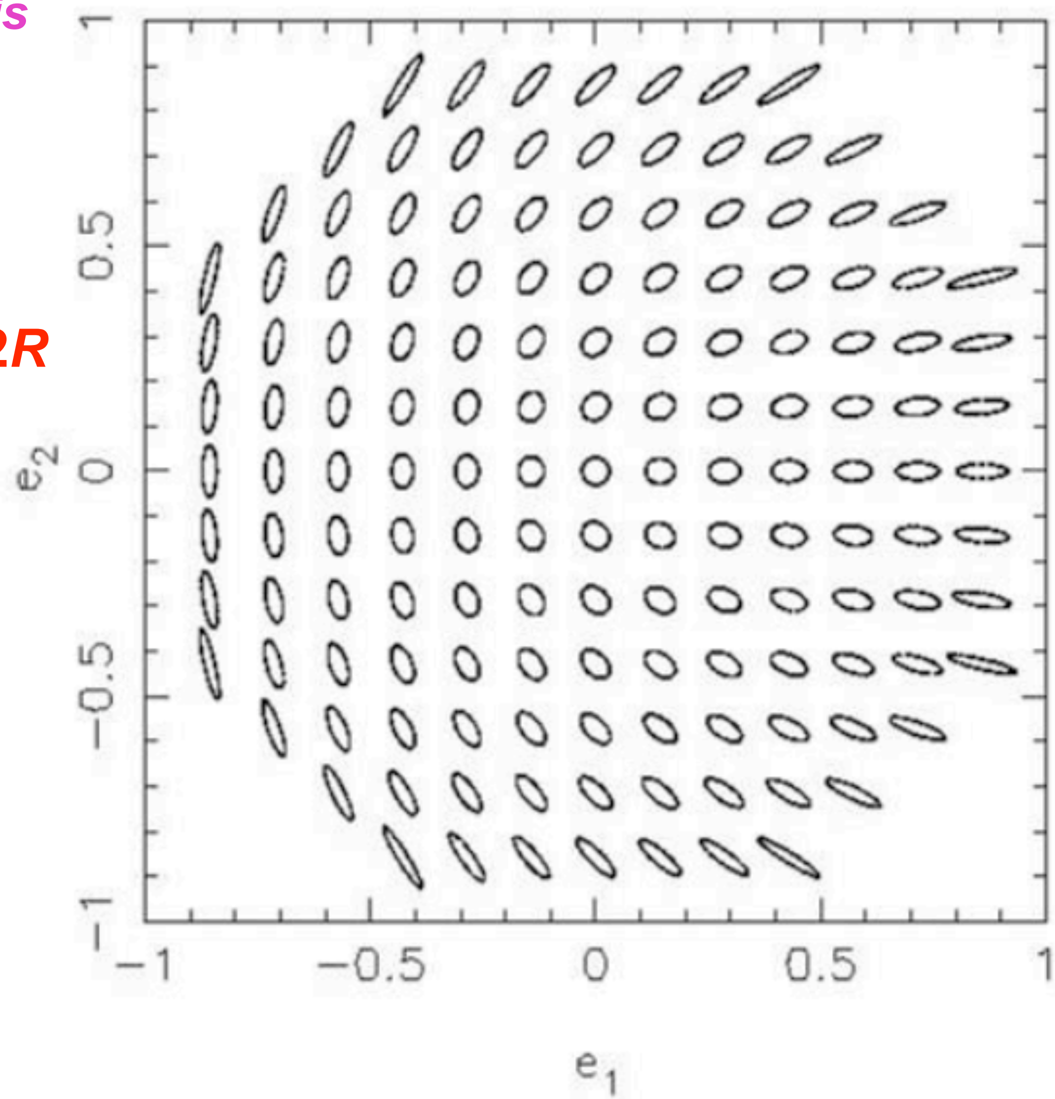
Main source of statistical error is "shape noise" = $e_{rms} \approx 0.37$ (per ellipticity component)

$$e^{\rm obs} = e^{\rm source} + \gamma\, 2R$$

$$< e^{\rm source} >= 0$$

$$2R\gamma =< e^{\rm obs} >$$

We use responsivity R = 0.86 as in previous SDSS lensing studies



From weak lensing catalogue to DM and DE

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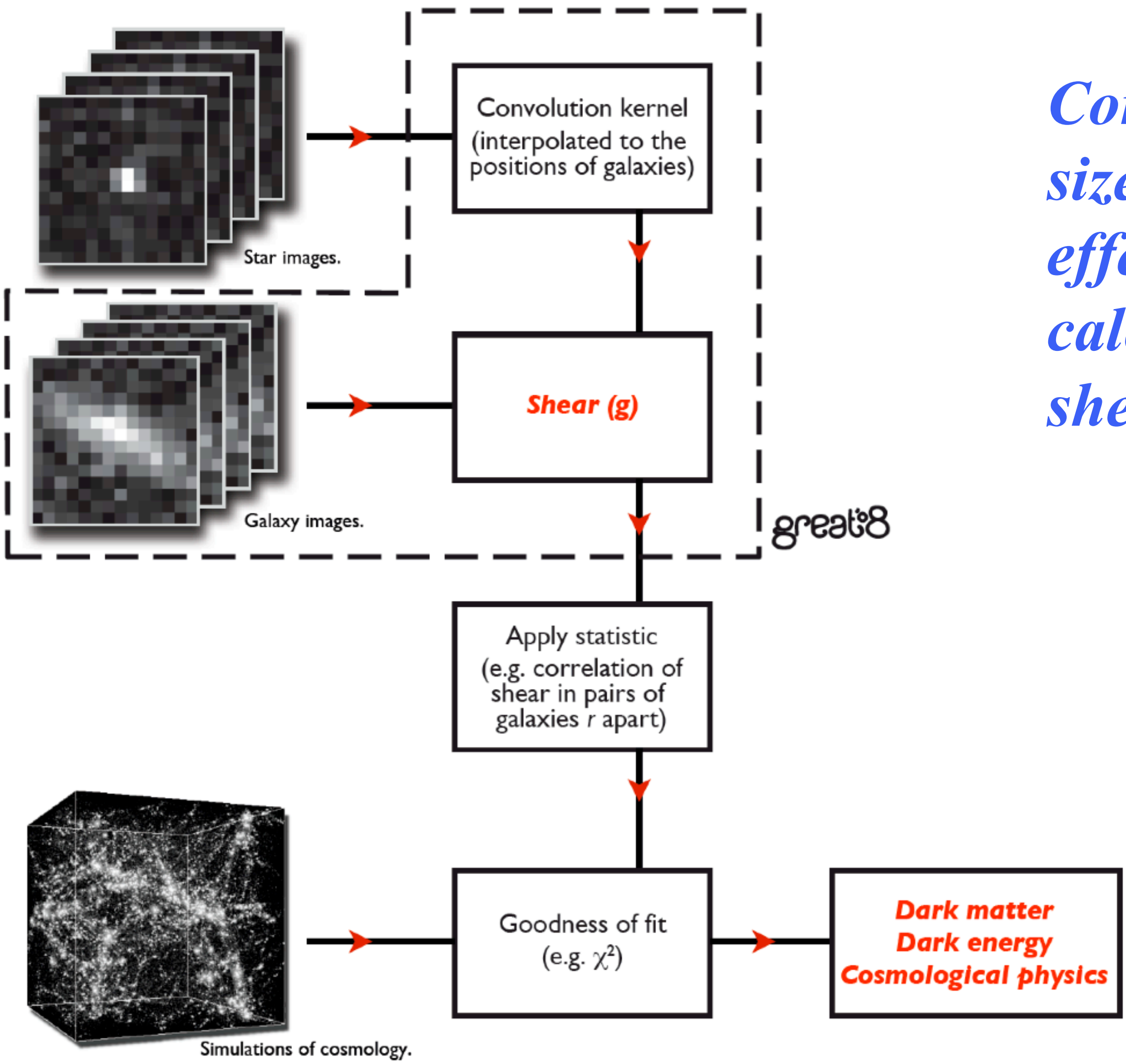
The broader context typical for cosmological measurements



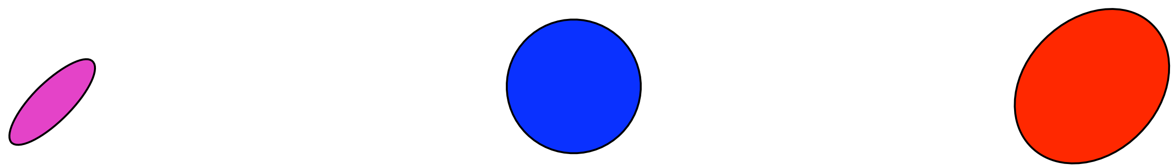
Correct galaxy sizes/shapes for effects of PSF and calculate the cosmic shear field

Example effects of the point spread function (PSF) on galaxy shapes and sizes

Original small elliptical galaxy

Convolved by larger, circular PSF

Dilution: result is larger, less elliptical observed galaxy



Original circular galaxy

Convolved by elliptical PSF

Anisotropy: result is elliptical observed galaxy

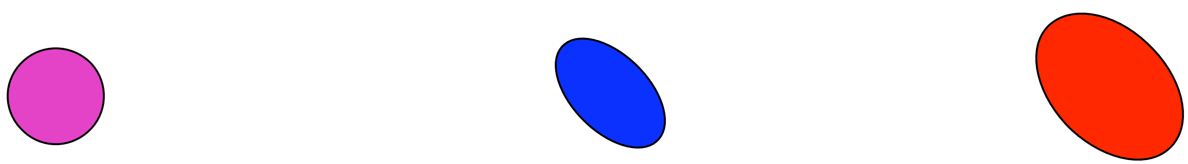
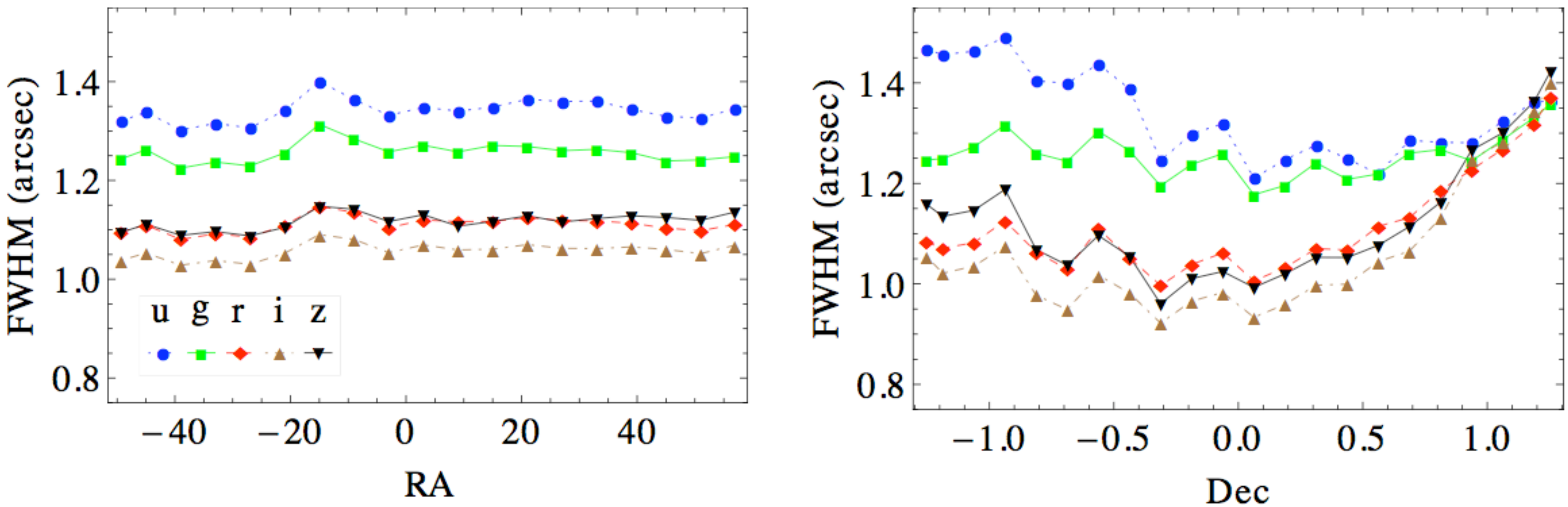


Image quality (FWHM of stars)

Center for Particle Astrophysics

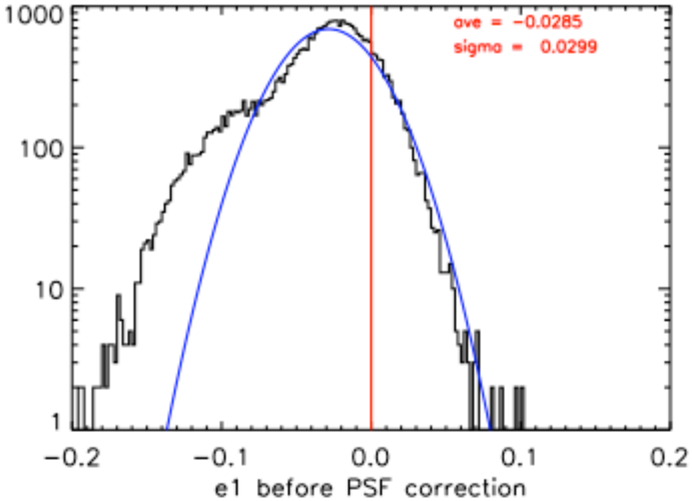
i-band image quality is best (stellar FWHM, or seeing, ≈1.05'')
and we use the i-band data for the cosmic shear analysis

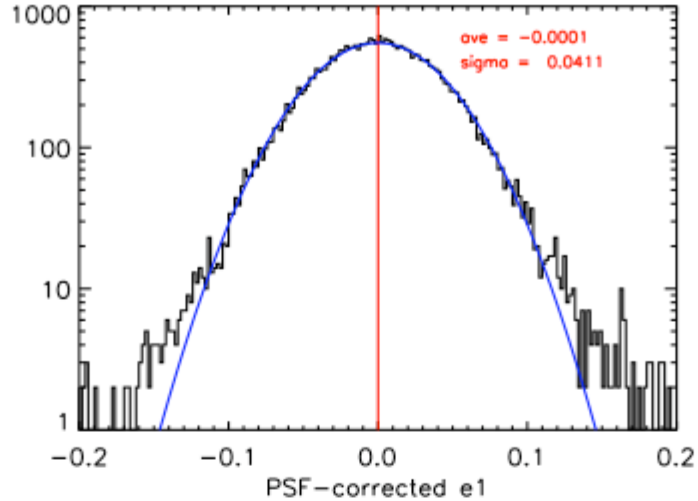


Note the spatial dependence of the point spread function (PSF) and hence image quality, in particular vs. Declination (perpendicular to scan direction; caused by camera optics)

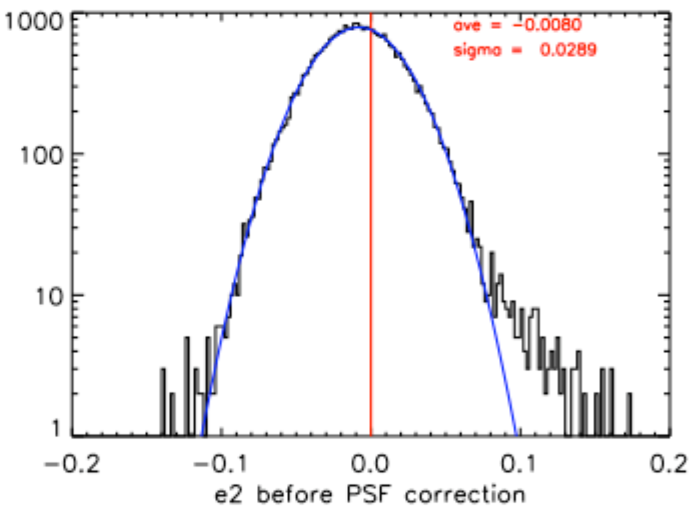
Galaxy ellipticity distributions

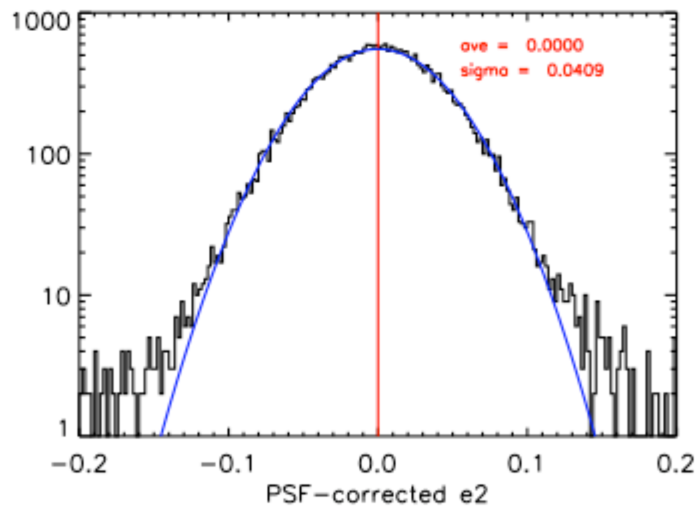
Before PSF correction | *After PSF correction*





e_1 component

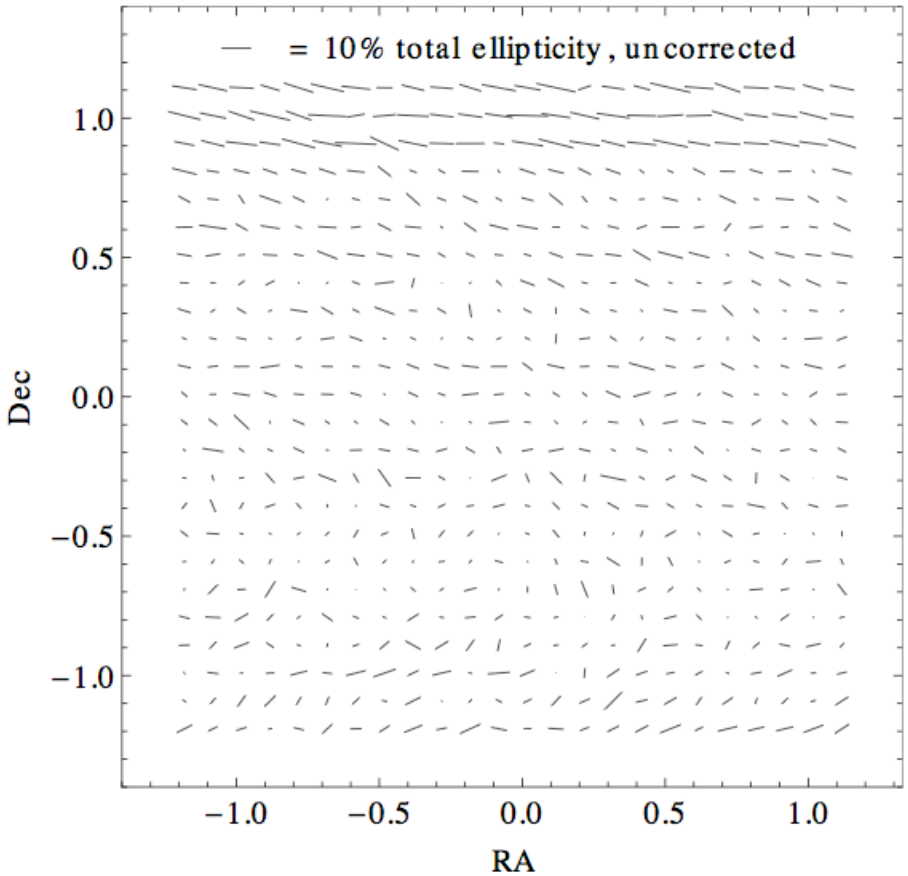




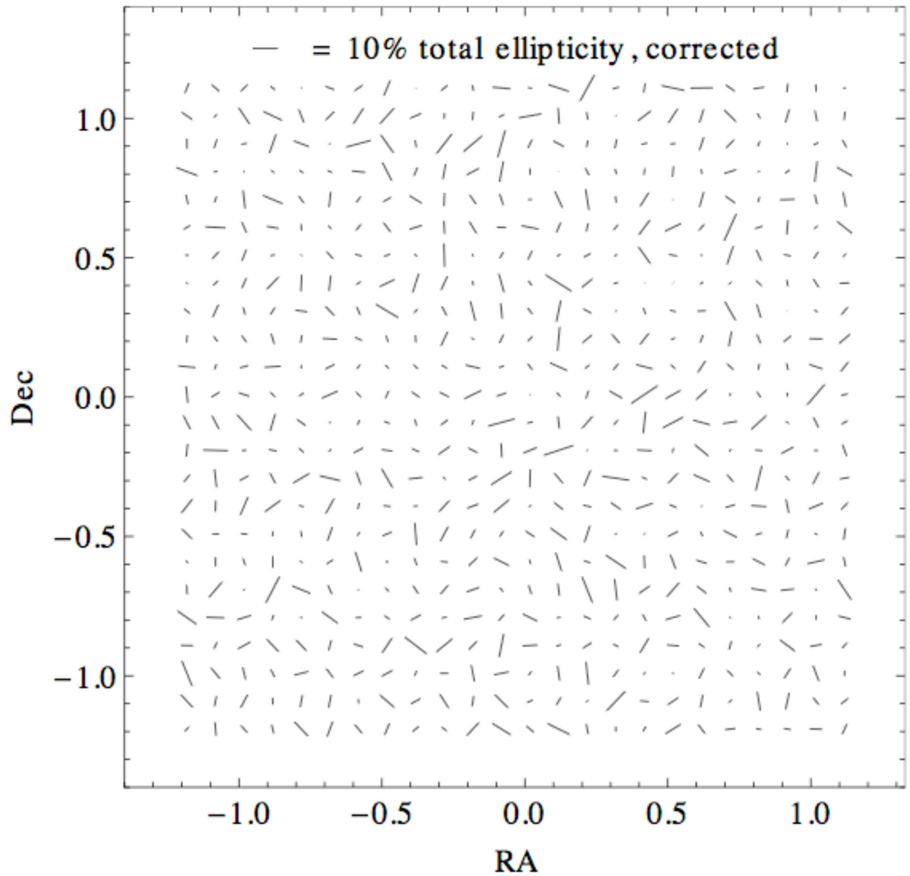
e_2 component

Galaxy ellipticity whisker plots

Before PSF correction



After PSF correction



Cosmic shear galaxy sample

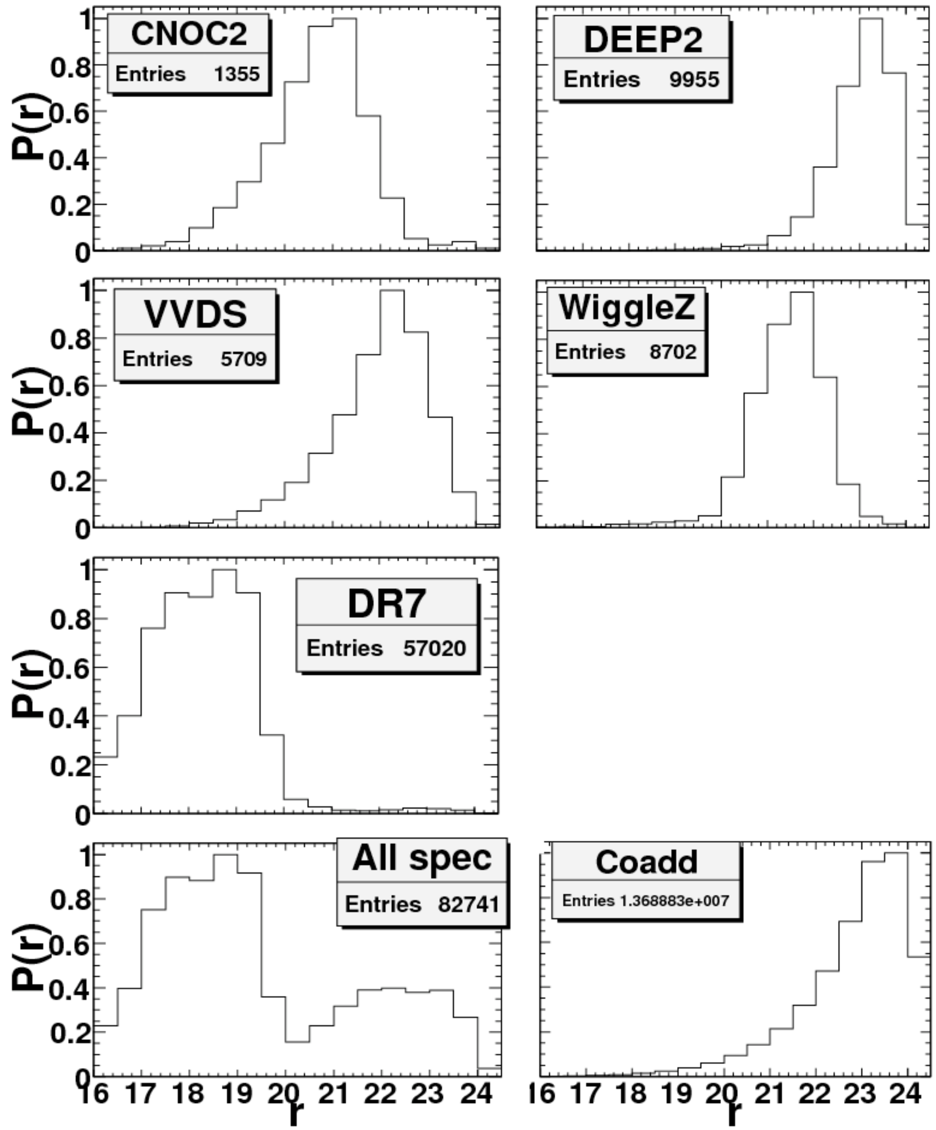
- Galaxies with *i*-band magnitude $18 < i < 24$
- Observed (pre-PSF corrected) galaxy size > 1.5 times the PSF size
- PSF-corrected galaxy ellipticities $|e_1| < 1.4$ and $|e_2| < 1.4$
- Photo-*z* errors $\sigma_z < 0.15$ and < 0.2 ==> 3.70 and 4.69 million galaxies total, respectively
- Over 275 deg^2 area ==> 3.7 and 4.7 galaxies per arcmin^2
  - Cf. expected 10 galaxies per arcmin^2 over 5000 deg^2 for DES cosmic shear sample

Coadd photometric redshifts: Reis et al. (2011), arXiv:1111.6620

- Coadd galaxy sample depth is too faint for full spectroscopic redshift coverage
- Need to know redshift distribution of galaxies in order to derive cosmology constraints
- Photometric redshifts: estimates of redshifts from magnitudes and colors, instead of spectra
- Use artificial neural network, plus training set of galaxies with known spectroscopic redshifts, to derive photo-z solution and to estimate photo-z errors, using methods of Oyaizu et al. (2008a,b), previously applied to SDSS single-pass data

Photo-*z* training set

Distributions vs. r-band magnitude

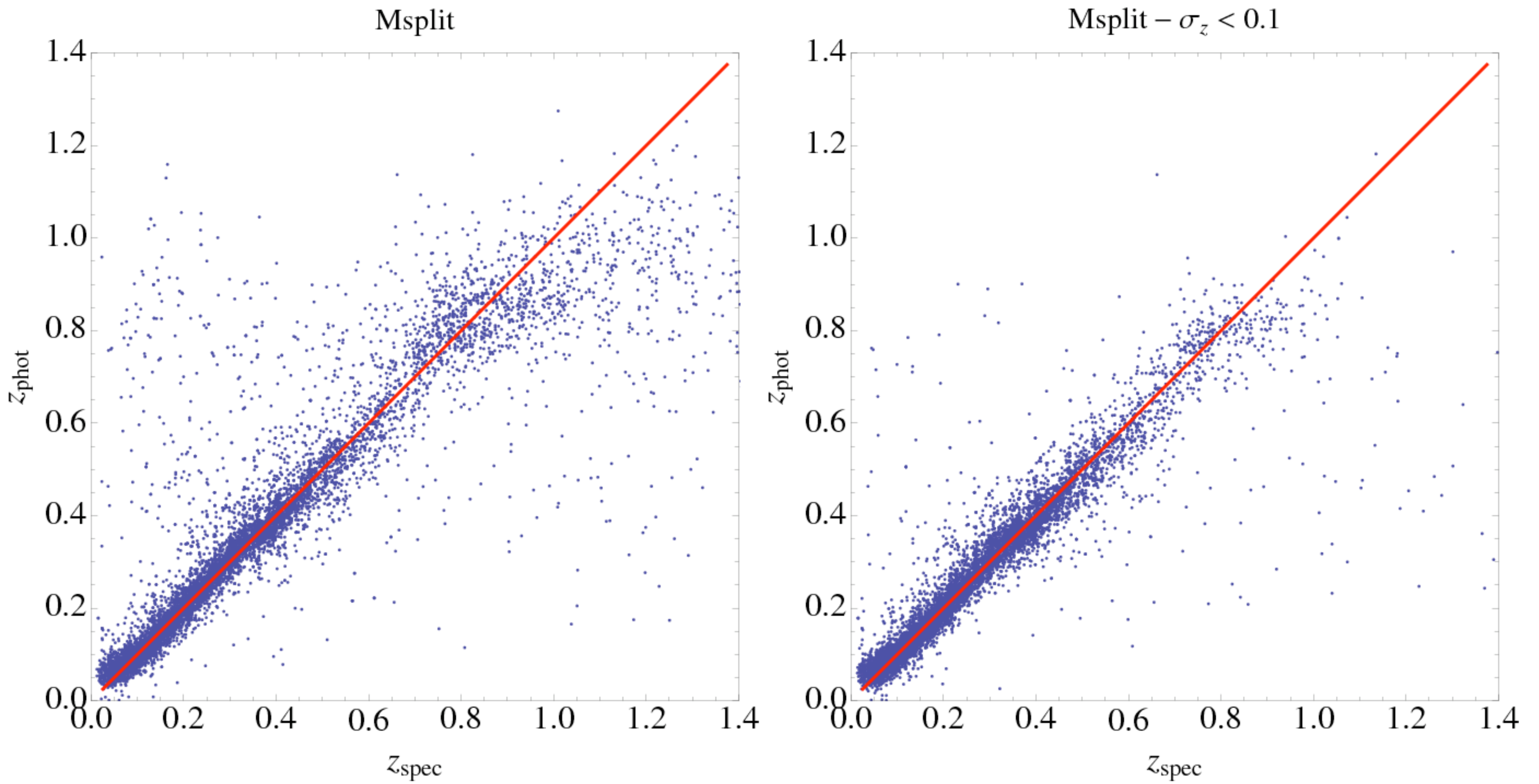


Training set of 83,000 galaxies with spectroscopic redshifts from 5 surveys

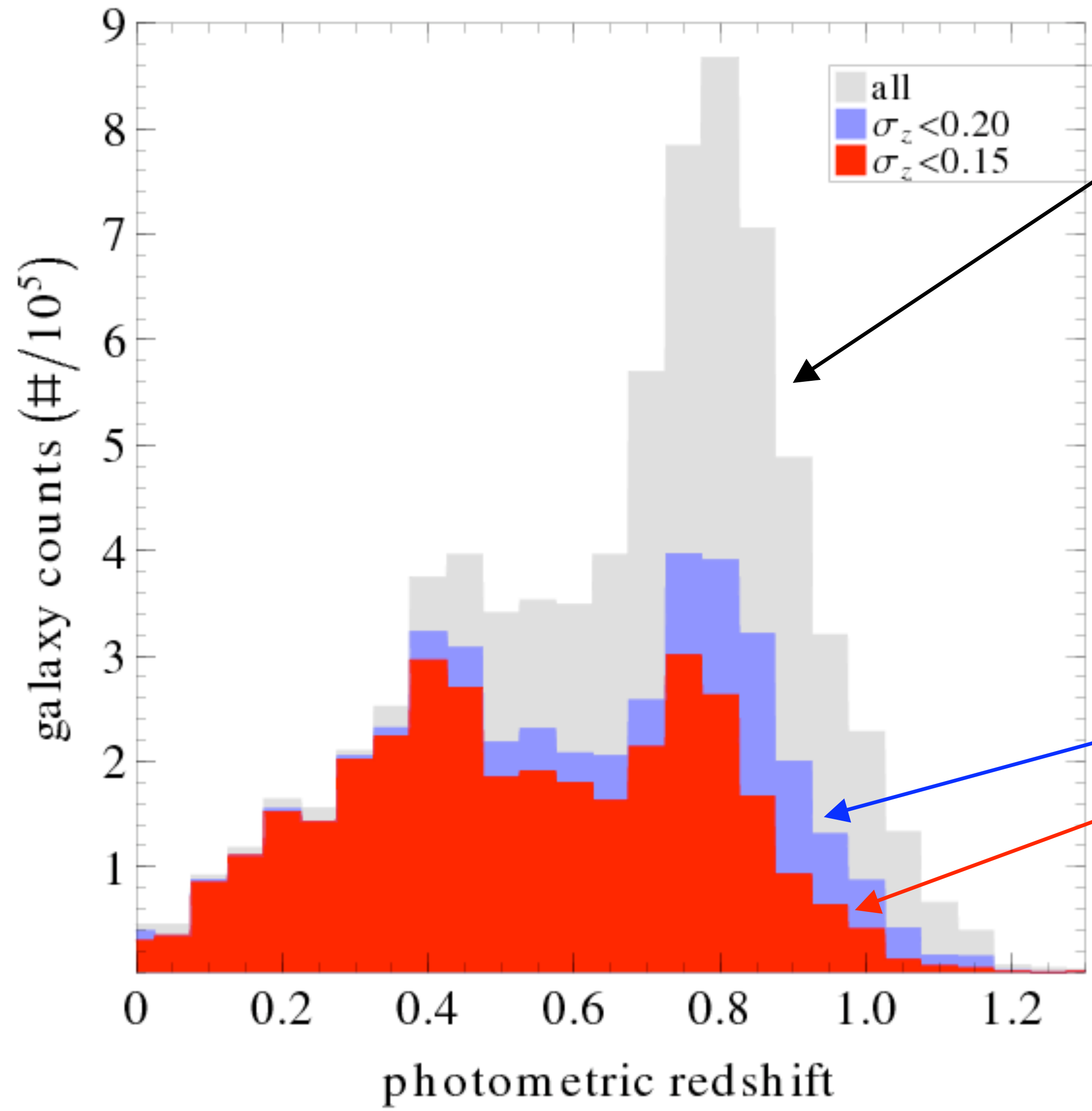
Used for calibration of the magnitude-redshift relationship and for estimates of photo-z errors

Photo-*z* vs. spectro-*z*

Photo-z quality improved and outliers reduced by using cuts on estimated photo-z errors (right panel)



Redshift distributions



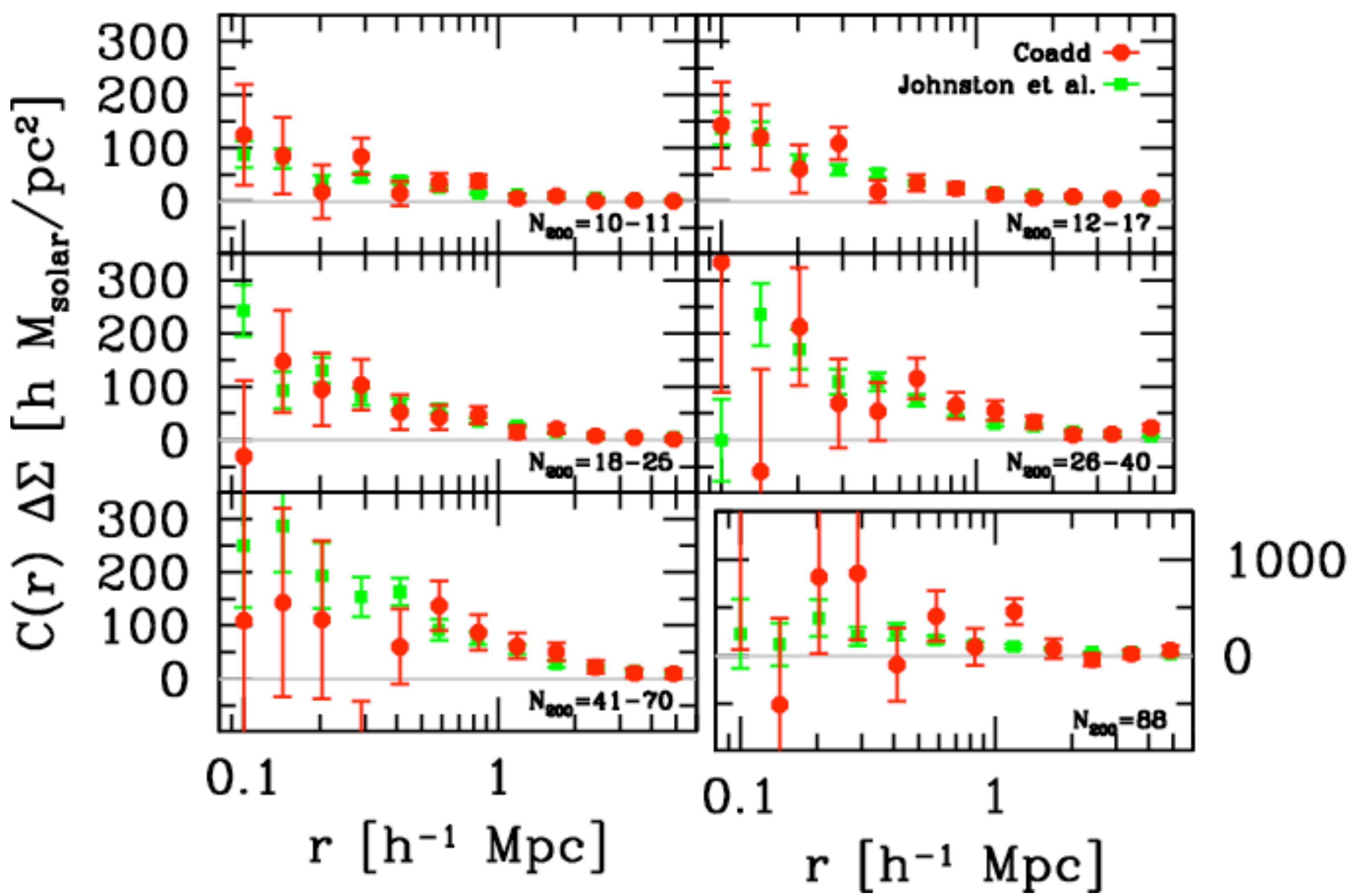
Redshift distribution less reliable if sample not culled of galaxies with large estimated photo-z errors σ_z

Make cuts so samples have more reliable redshift distributions, though fewer galaxies:

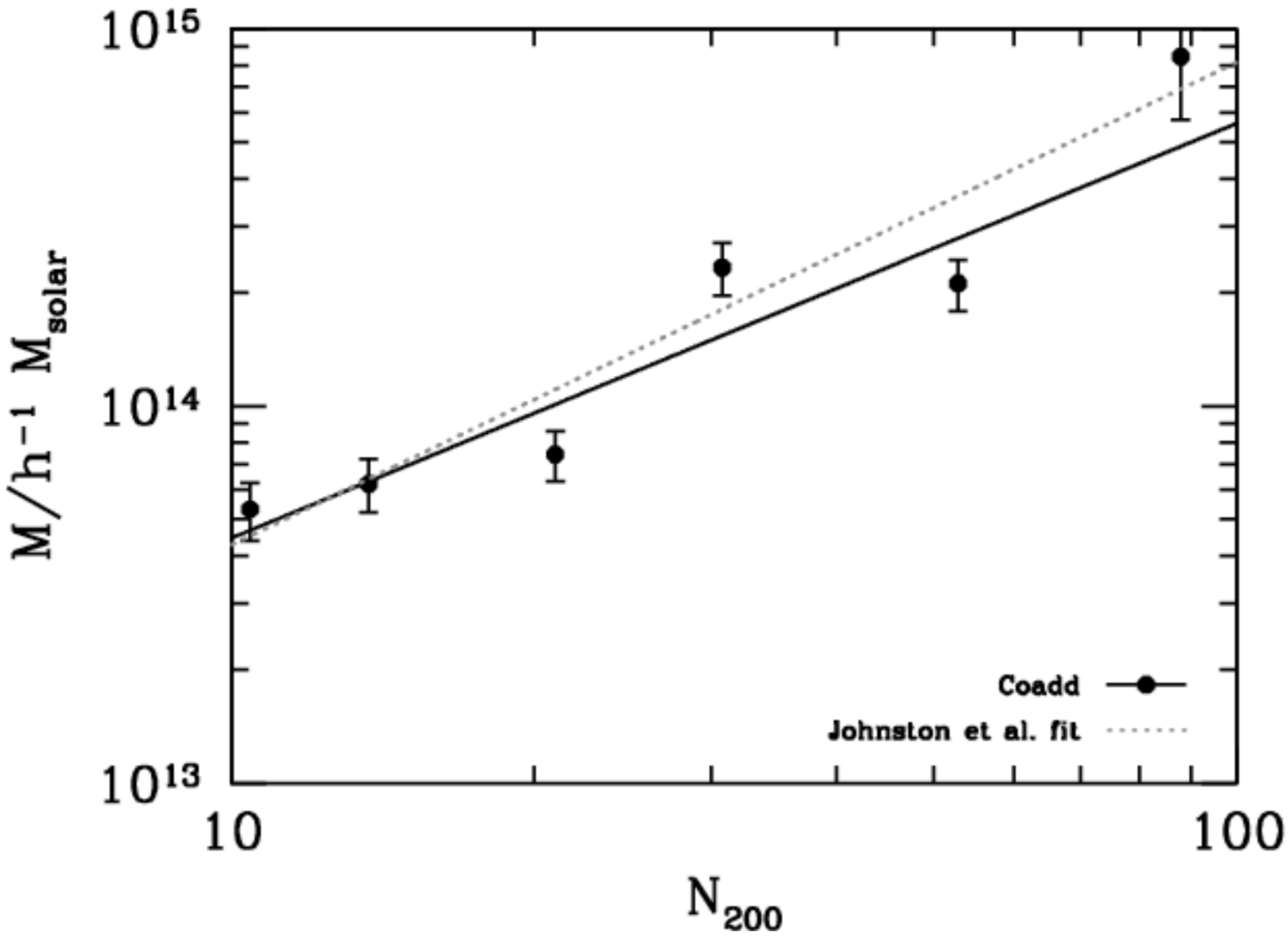
$\sigma_z < 0.20$ 4.7 million

$\sigma_z < 0.15$ 3.7 million

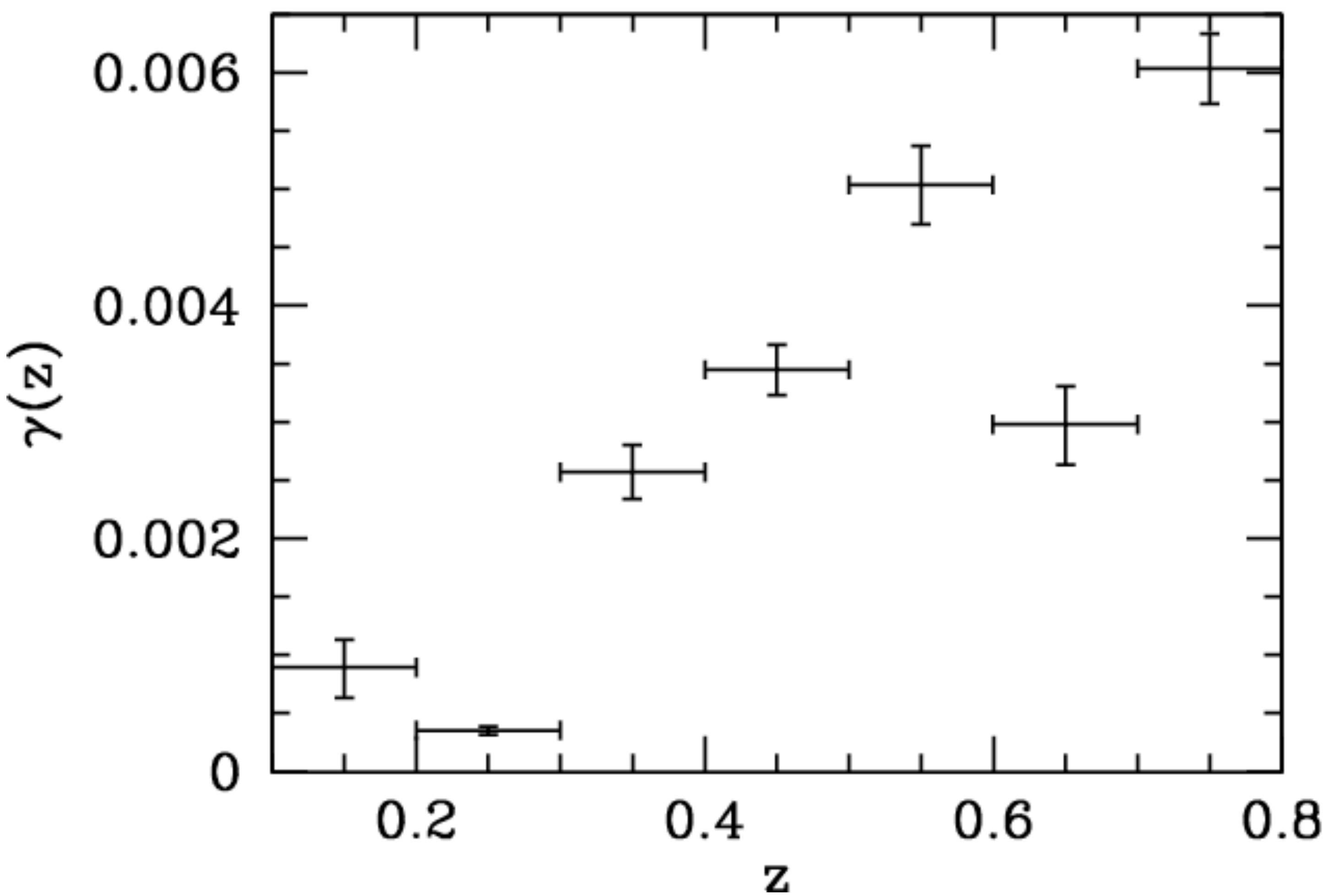
Cluster weak lensing
Simet et al. (2011), arXiv:1111.6621



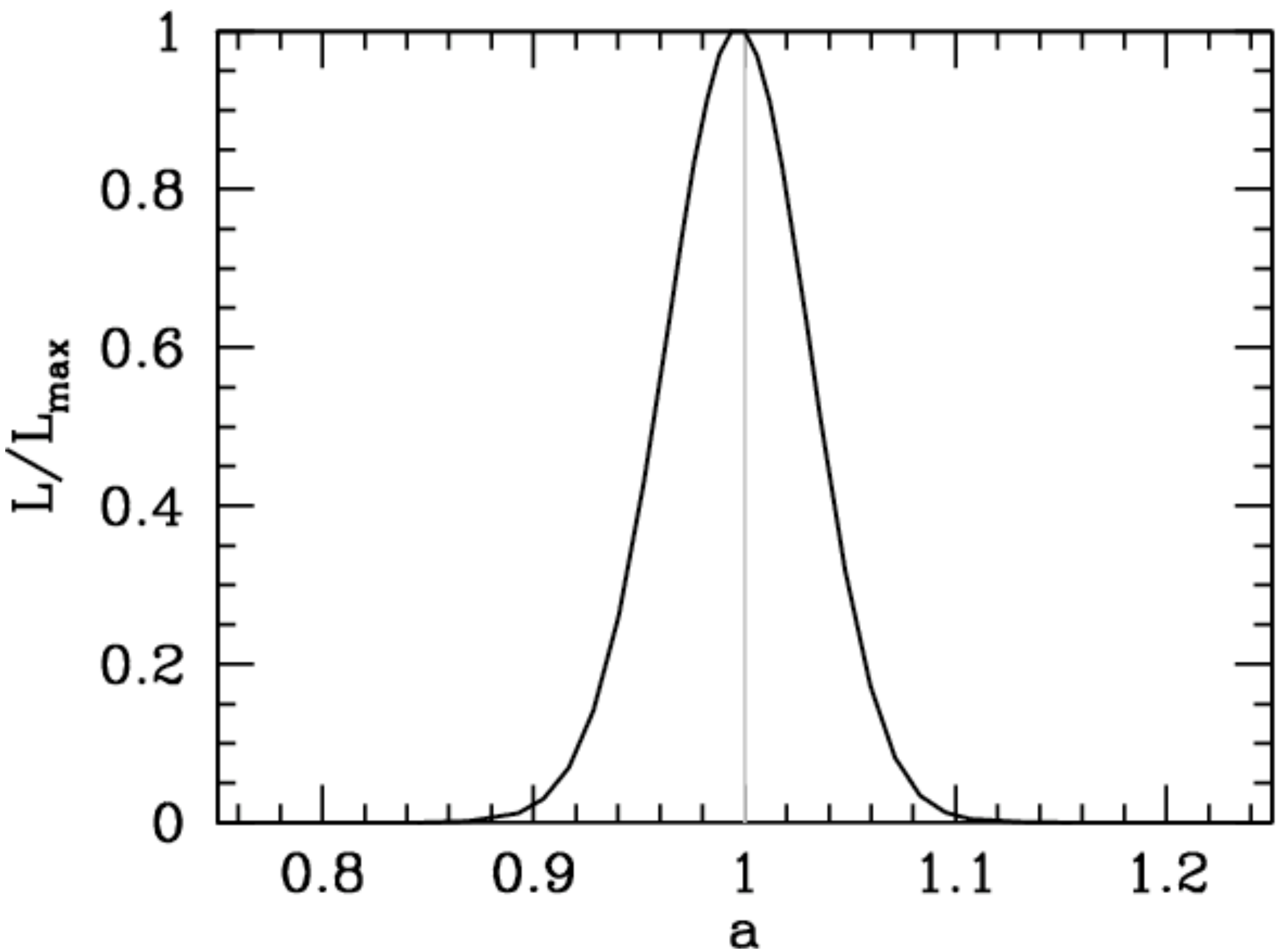
Mass vs. richness



Shear vs. redshift

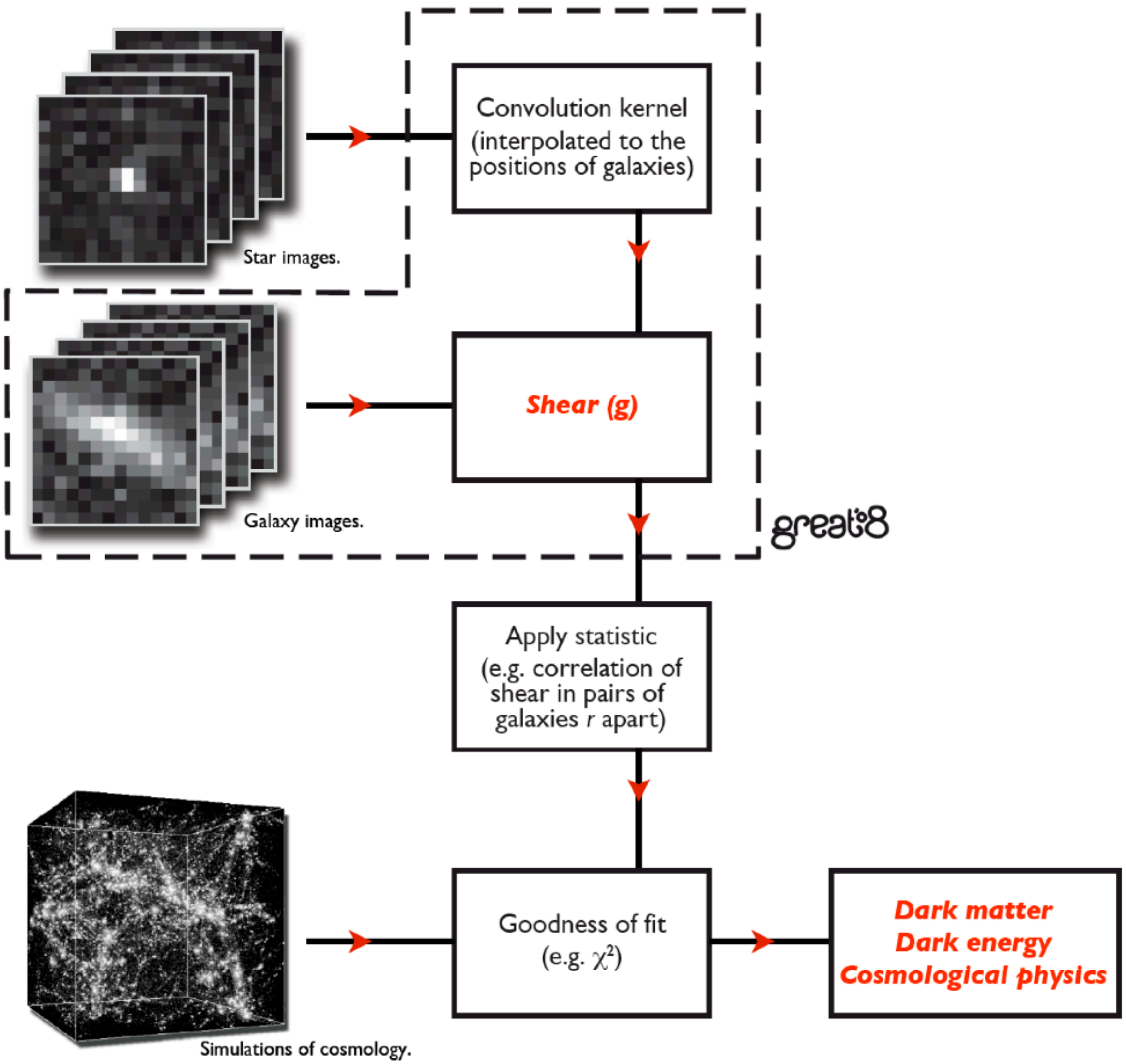


Tomography likelihood



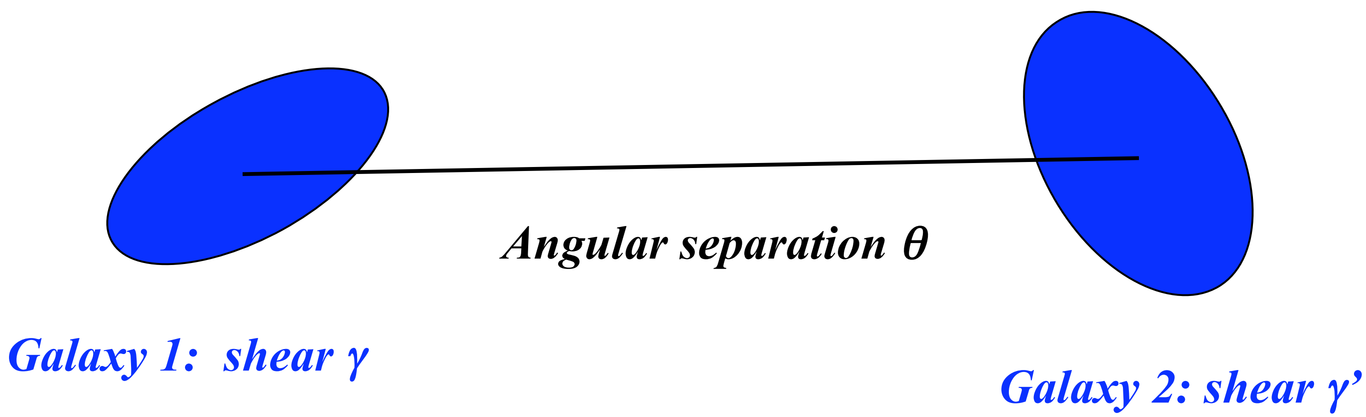
From weak lensing catalogue to DM and DE

A full weak lensing pipeline:
The broader context typical for cosmological measurements



Calculate statistics of cosmic shear field

Shear-shear correlation function



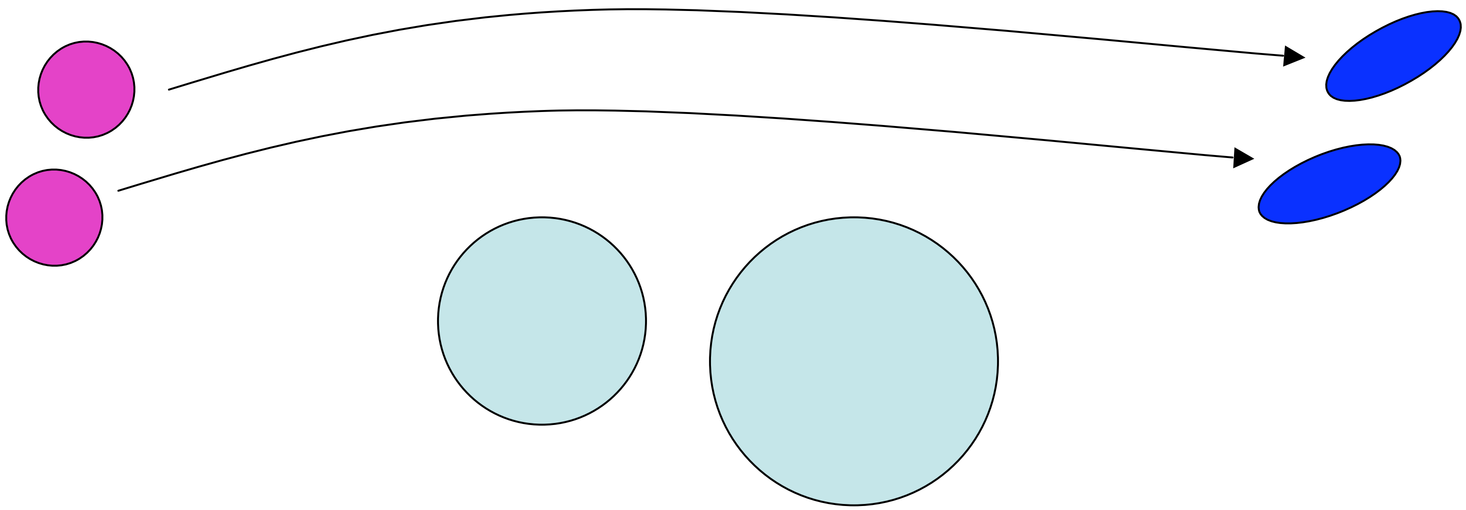
Shear-shear correlation function $\xi(\theta) = < \gamma\, \gamma' (\theta) >$
where average is over galaxy pairs separated by θ

The correlation function ξ is a simple statistical measure of the cosmic shear field

Correlation function at smaller separations

Closely separated pair of circular galaxies

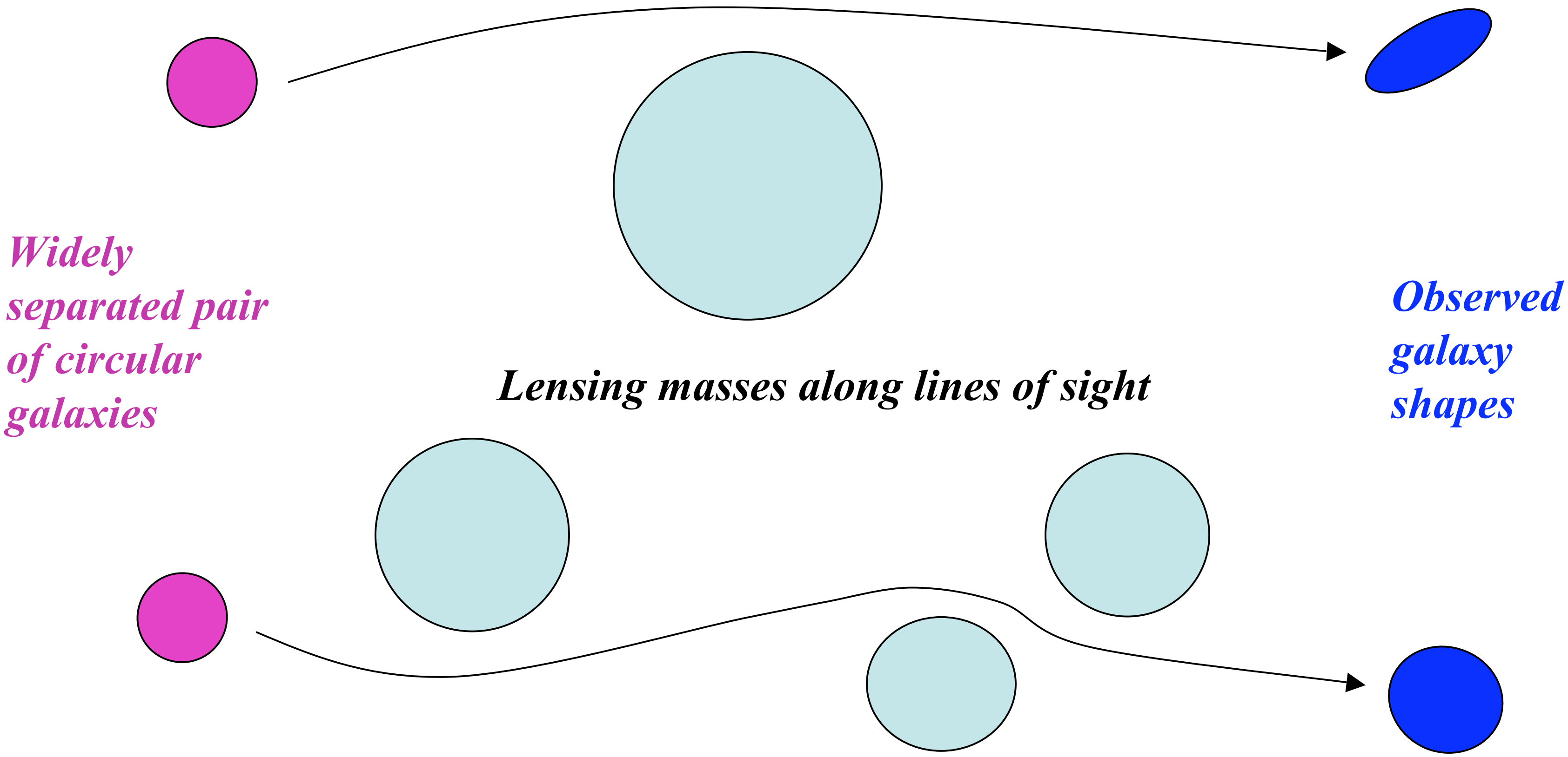
Observed galaxy shapes



Lensing masses along line of sight

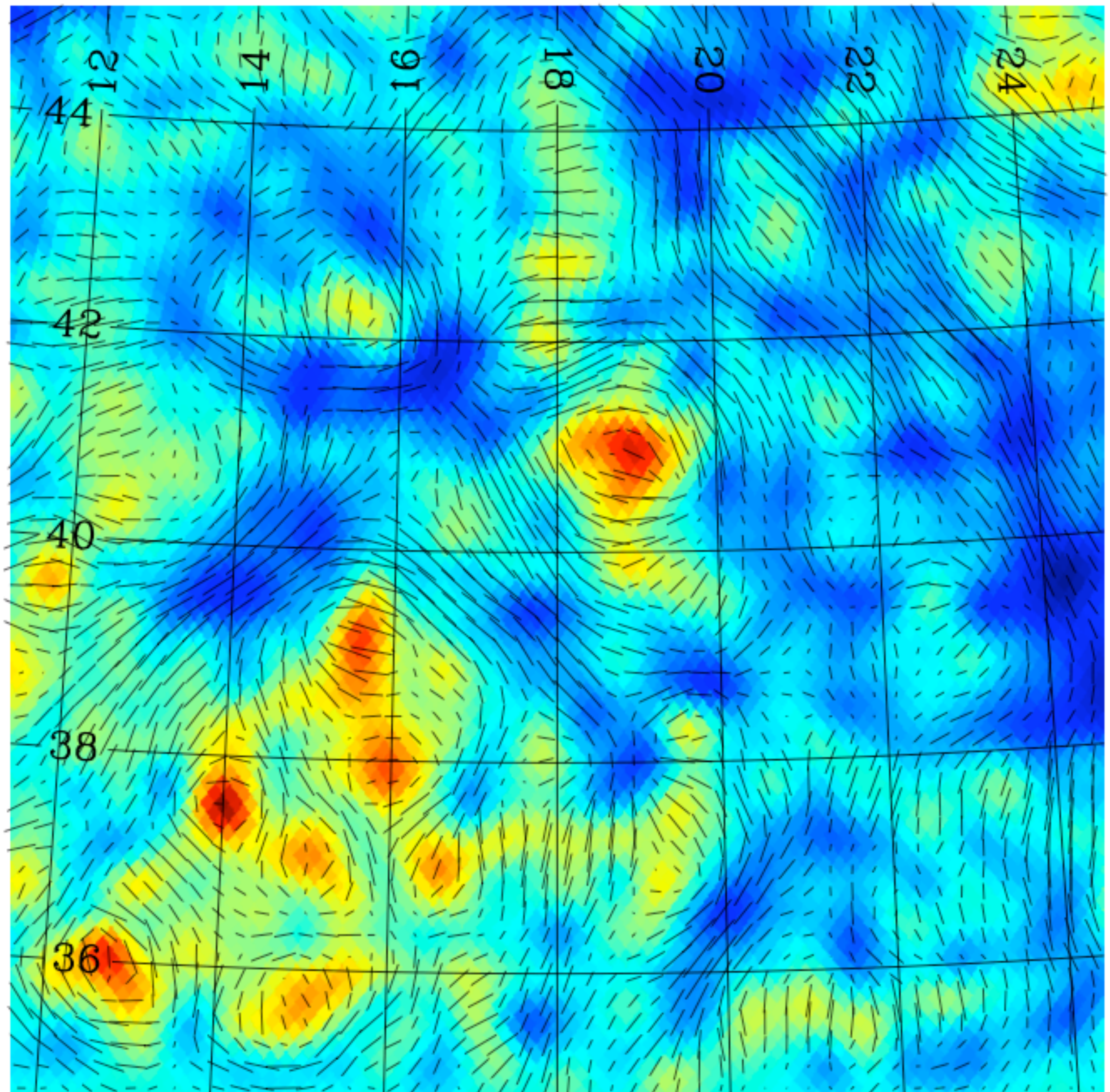
Closely separated galaxy pairs are sheared similarly by common structures along the line of sight ==> so observed shapes (shears) are more correlated ==> larger shear-shear correlation function at small separations

Correlation function at larger separations



Widely separated galaxy pairs are less likely to see the same structures along the line of sight ==> so observed shapes (shears) are less correlated ==> smaller shear-shear correlation function at larger separations

Map of DES "DC6B" 200 deg^2 simulated convergence and shear fields



Colors indicates convergence ∝ surface mass density

red ==> high density
blue ==> low density

Black "whiskers" show lensing shear field

Whiskers indicate magnitude and direction of lensing distortions acting on galaxy shapes

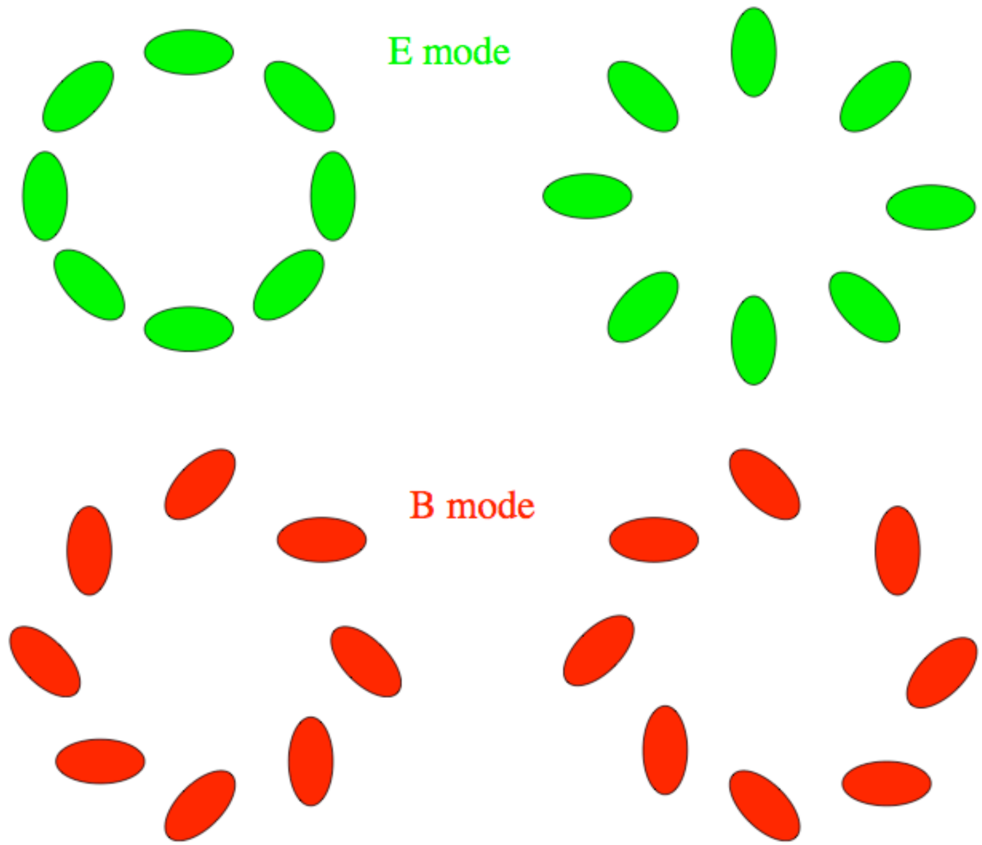
Figure from M. Becker

E and B modes

Lensing just produces an E-mode shear field

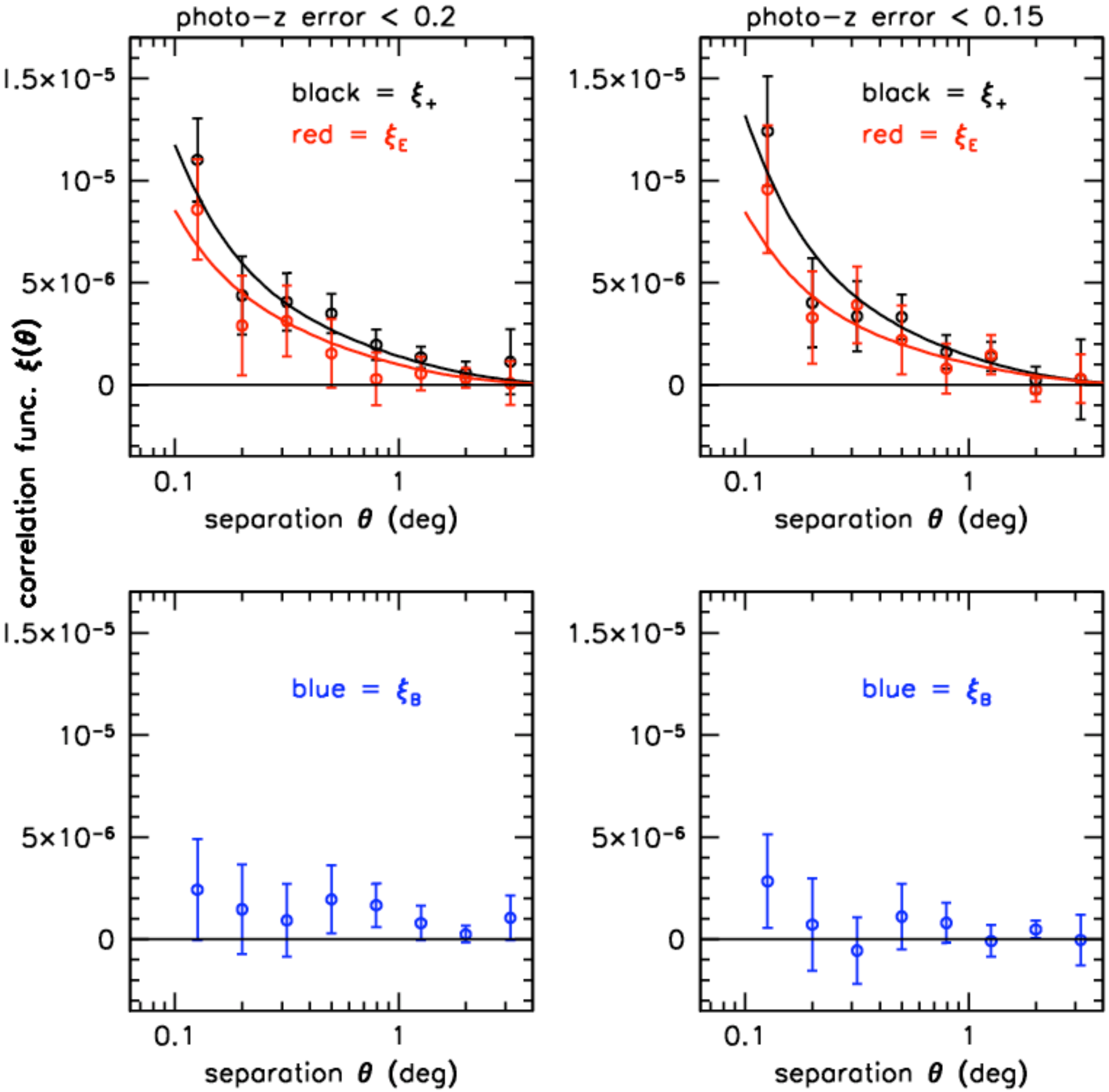
Check for nonzero B-modes as a test of systematics

Fig. 7 Example patterns from E-mode and B-mode fields (from [79]). Weak lensing only produces E-modes at any significant level, so the presence of B-modes can indicate systematic errors.



from Alan Heavens (arXiv:1109.1121v1)

Correlation function results

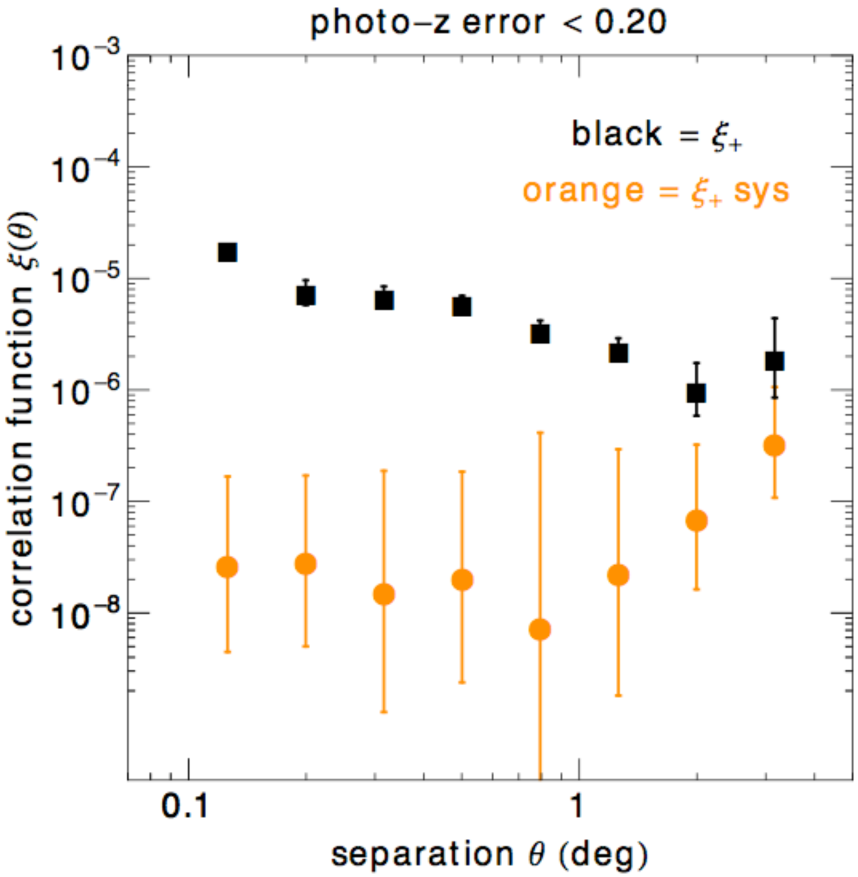


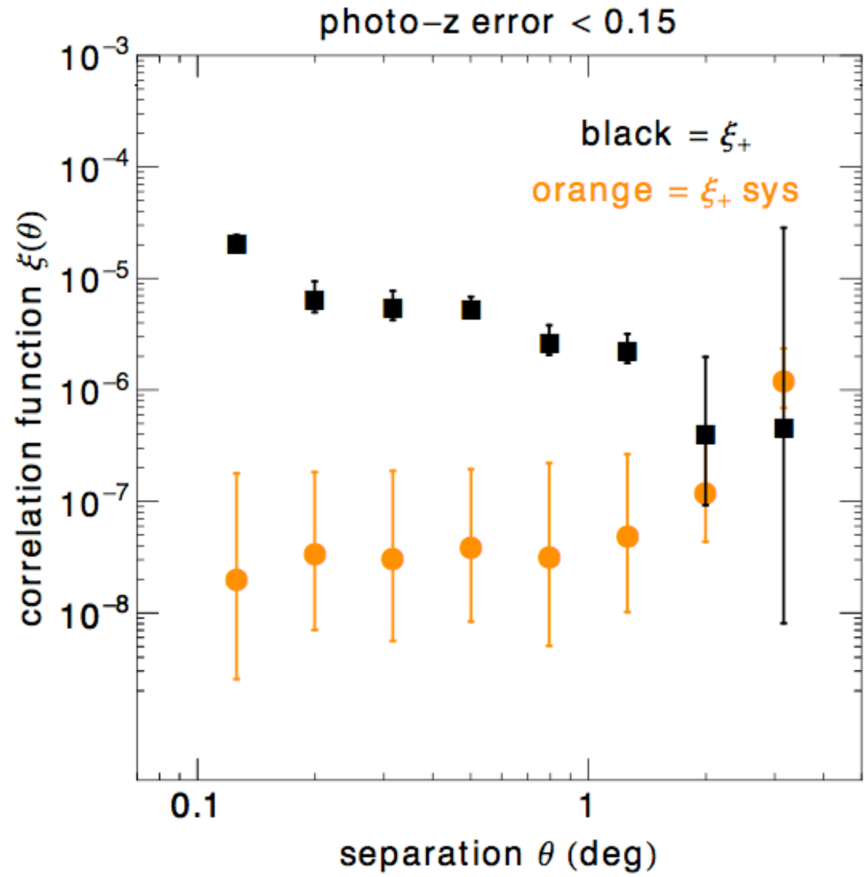
5σ detection of cosmic shear signal in the correlation function

$$\xi_+ = \xi_E + \xi_B$$

Appears to be some small B-mode systematic, though consistent with zero within the errors

Correlation function: PSF systematic

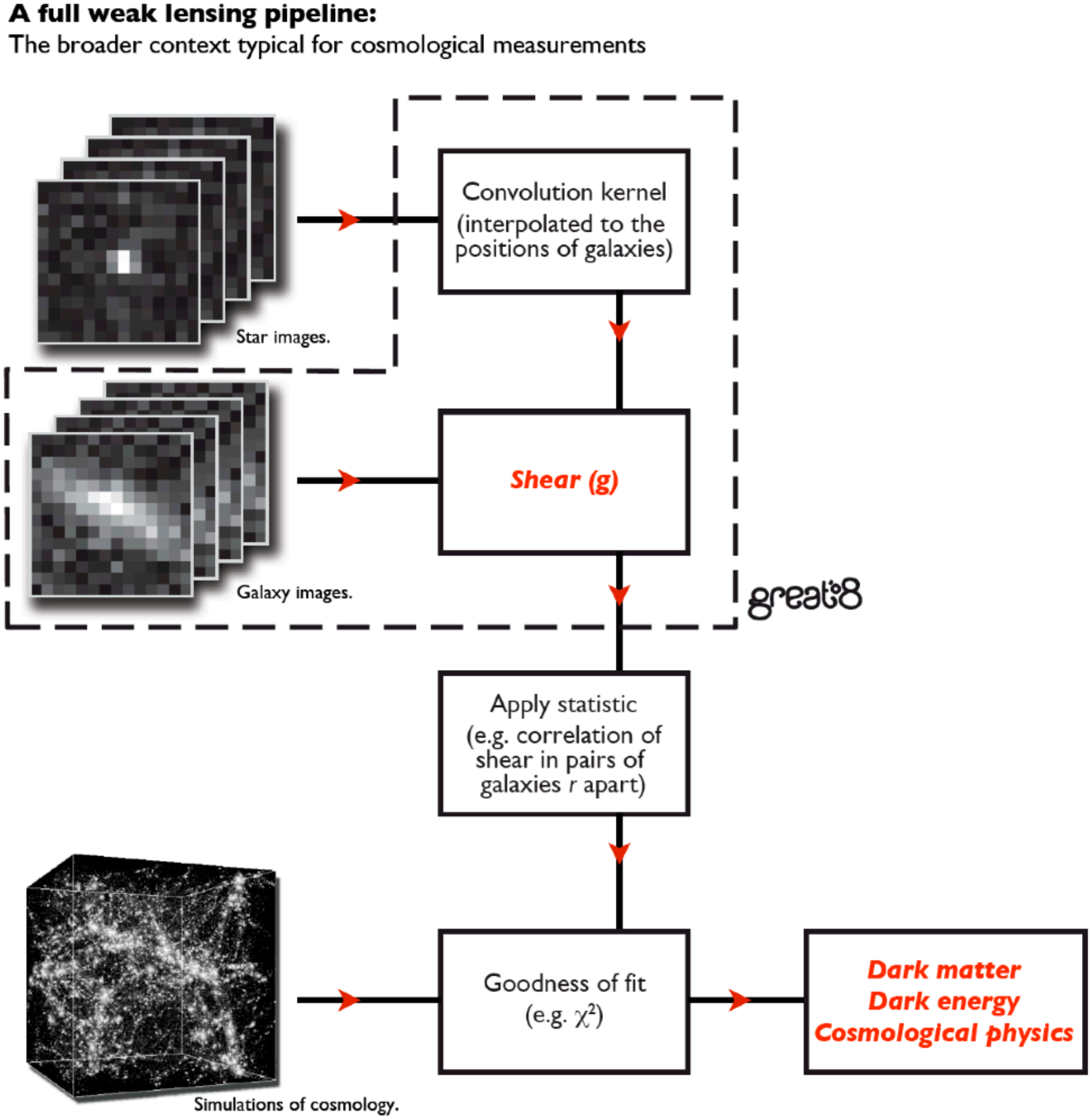




Orange indicates spurious correlation function induced by PSF systematics

Ok as systematic is negligible cf. cosmic shear signal on most scales, and on largest scales, statistical errors are large and we have verified negligible effect on cosmology fits

From weak lensing catalogue to DM and DE



Fit cosmology from shear statistics

Correlation function and power spectrum and cosmology

$$\underbrace{\xi_{\pm}(\theta) \equiv \xi_{\mathrm{tt}}(\theta) \pm \xi_{\times\times}(\theta)}_{\text{correlation functions}} = \frac{1}{2\pi}\int_0^{\infty} \mathrm{d}\ell\, \ell\, \underbrace{P_{\kappa}(\ell)}_{\text{convergence power spectrum}} J_{0,4}(\ell\theta),$$

correlation functions

convergence power spectrum: matter fluctuations after projection along line of sight

$$P_{\kappa}(\ell) = \frac{9}{4}\Omega_{\mathrm{m}}^2 \left(\frac{H_0}{c}\right)^4 \int_0^{\chi_{\lim}} \frac{\mathrm{d}\chi}{a^2(\chi)} P_{\delta}\left(\frac{\ell}{f_K(\chi)};\chi\right)$$
$$\times \left[\int_{\chi}^{\chi_{\lim}} \mathrm{d}\chi' n(\chi') \underbrace{\frac{f_K(\chi'-\chi)}{f_K(\chi')}}_{\text{distances}}\right]^2,$$

power spectrum: 3D matter fluctuations ==> growth of structure

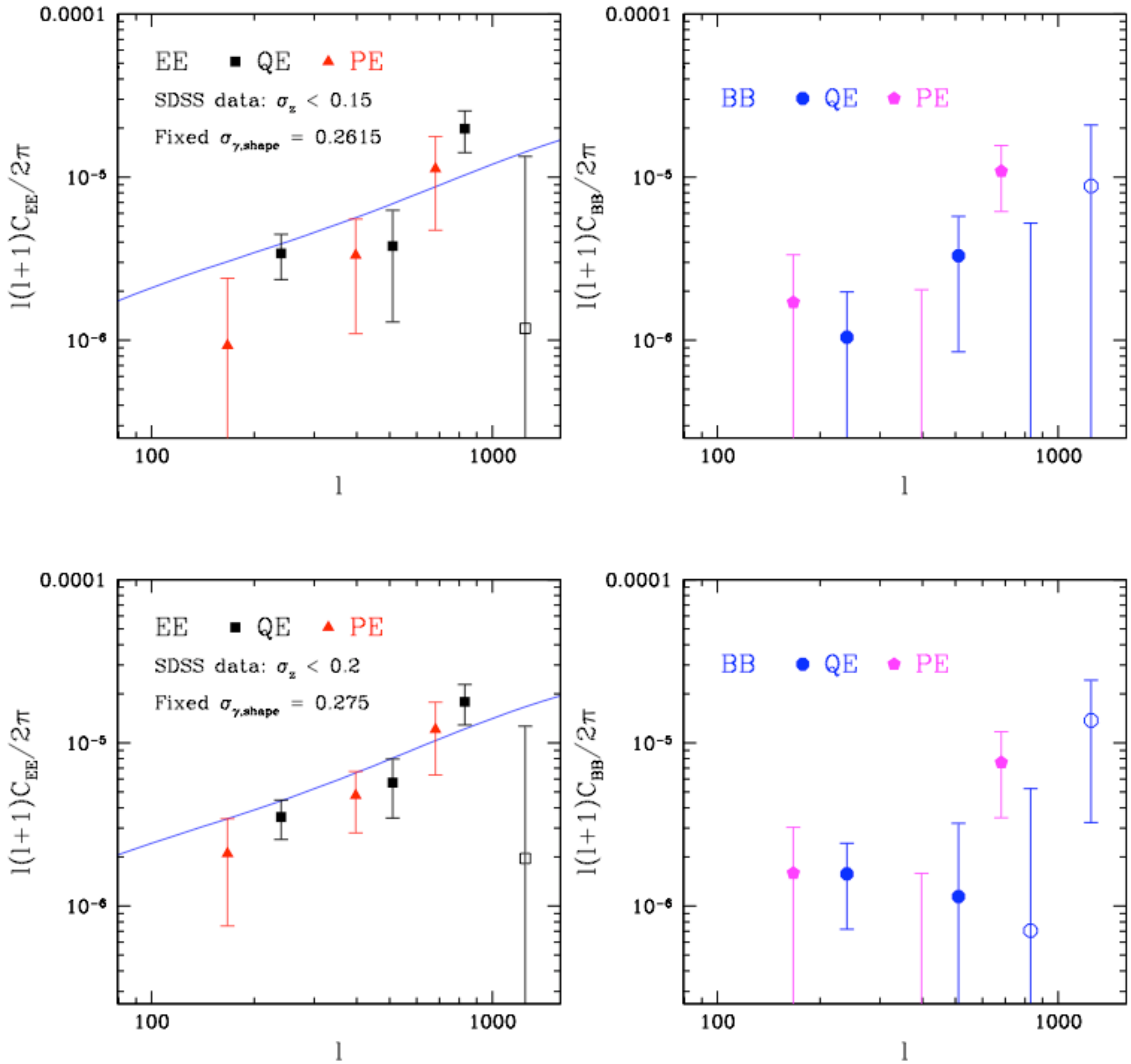
Galaxy redshift distribution

distances ==> geometry

COSMOLOGY PARAMETERS

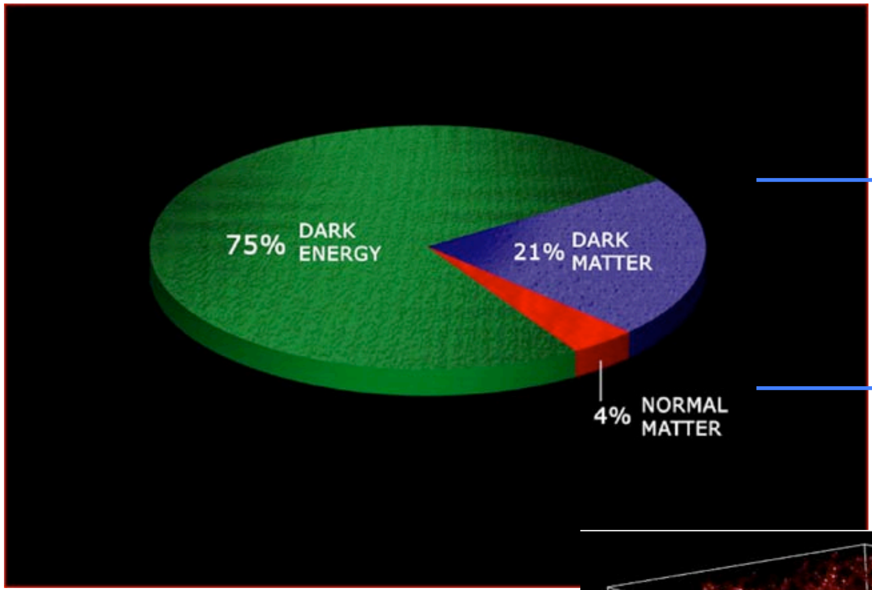
Power spectrum results

Also consistent detection of cosmic shear signal in E-mode power spectrum using two analysis methods: "Quadratic Estimator" (QE) and "Pseudo-C_l Estimator" (PE)



B-mode power spectrum results are ok

Current cosmic shear surveys are sensitive to combination of matter density and clustering amplitude



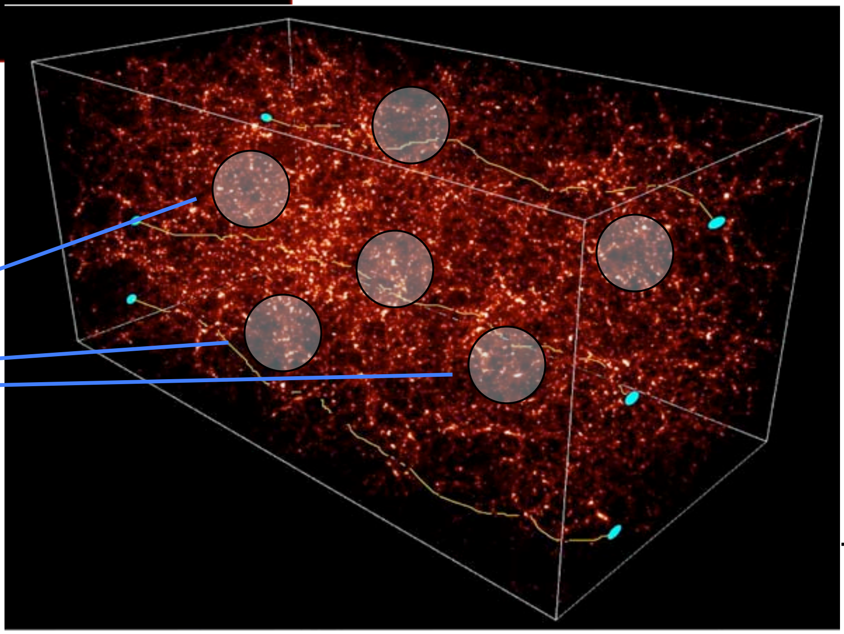
Credit: physicsforme.wordpress.com

Matter density Ω_M

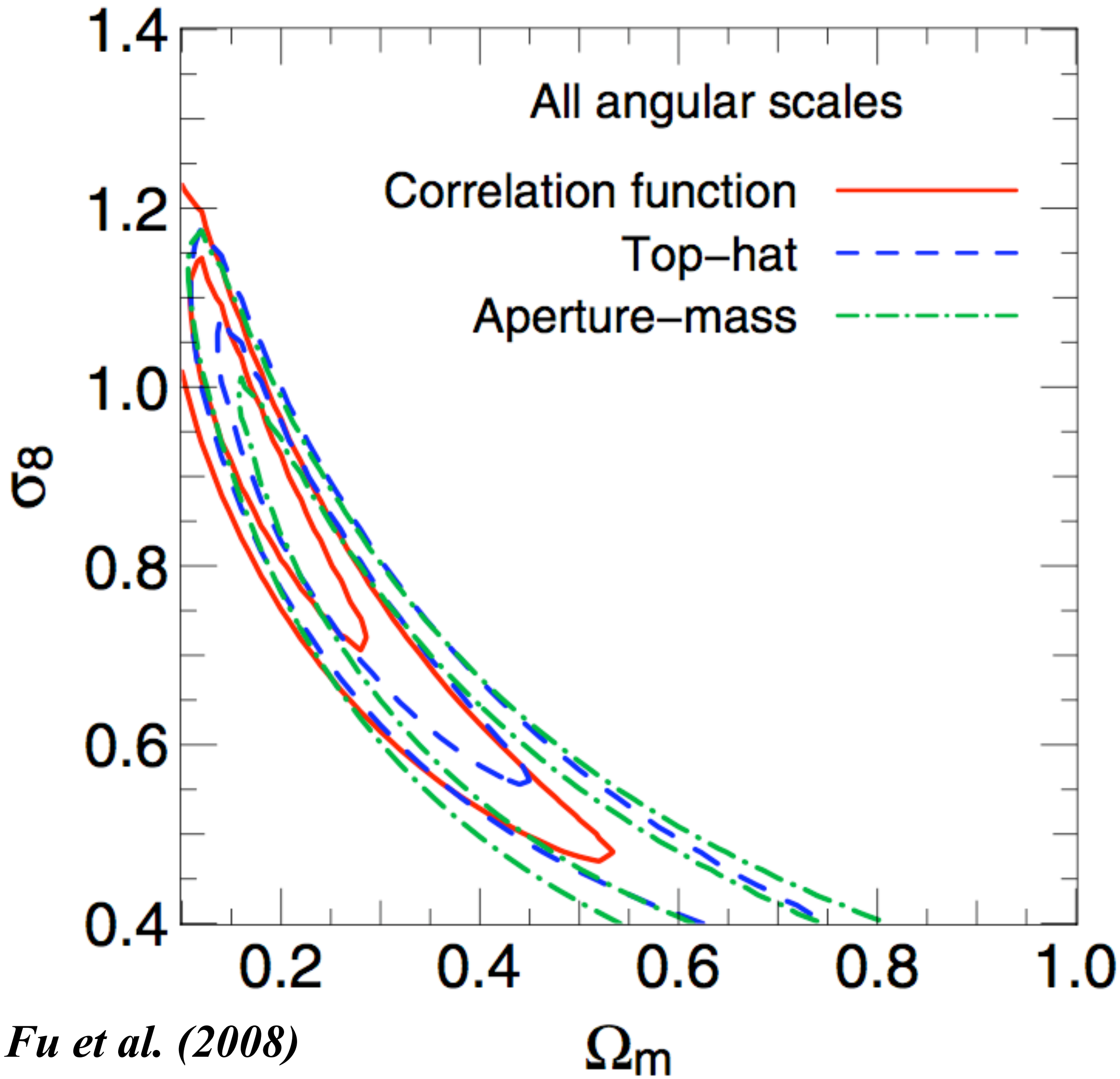
(Usually assume flatness: $\Omega_M + \Omega_\Lambda = 1$)

Clustering amplitude σ_8

rms matter density fluctuation in spheres of radius 8 Mpc/h



Combination of Ω_M and σ_8



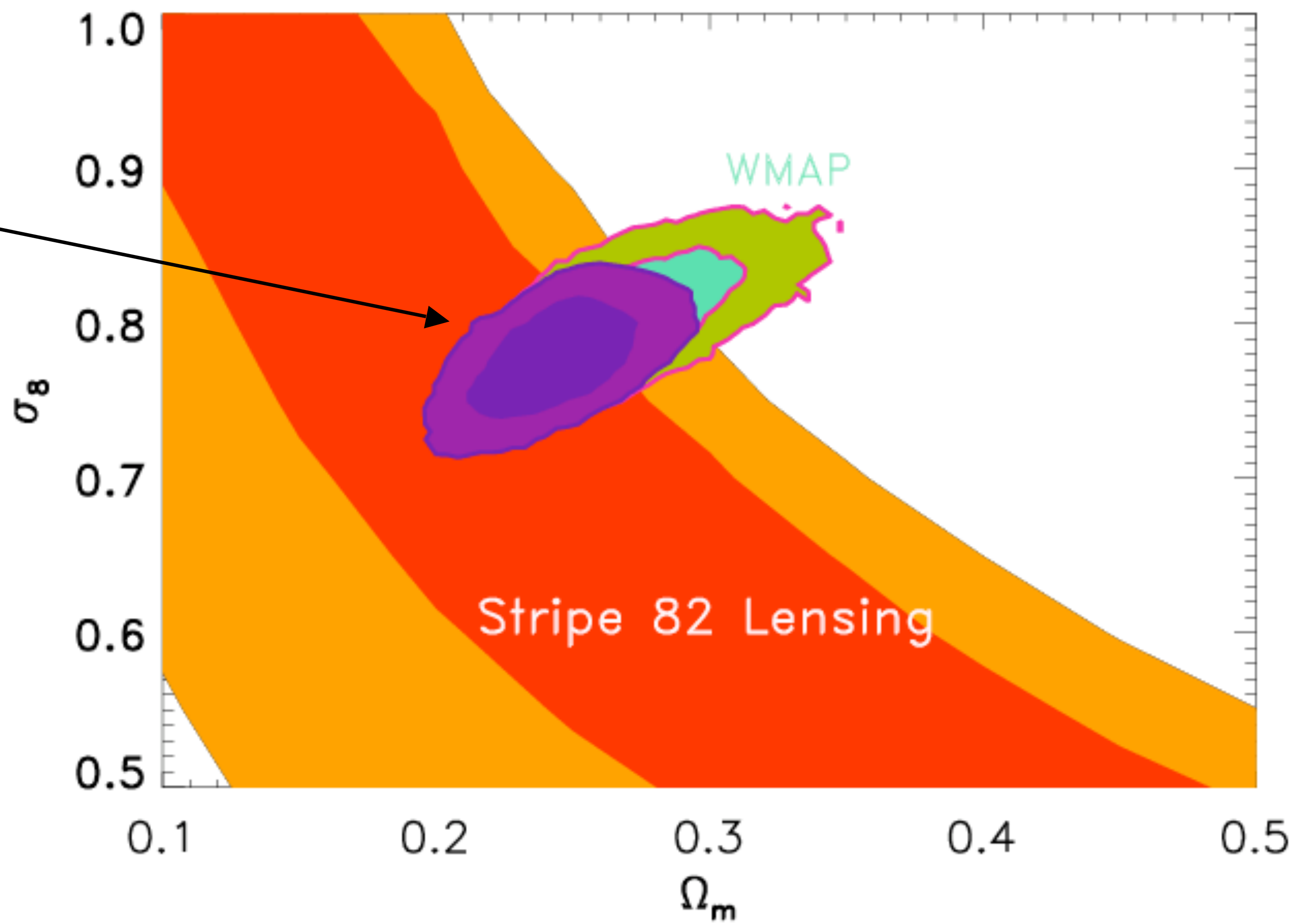
Fu et al. (2008)

Current cosmic shear surveys mainly constrain the combination $\sigma_8\ \Omega_M^{\alpha}$ where $\alpha \approx 0.5$-0.7 depending on degeneracy direction for given method and data set

1σ and 2σ cosmology contours

Coadd cosmic shear consistent with WMAP 7-year results (Komatsu et al. 2011)

Combined constraint prefers slightly lower matter density and clustering amplitude, cf. WMAP alone

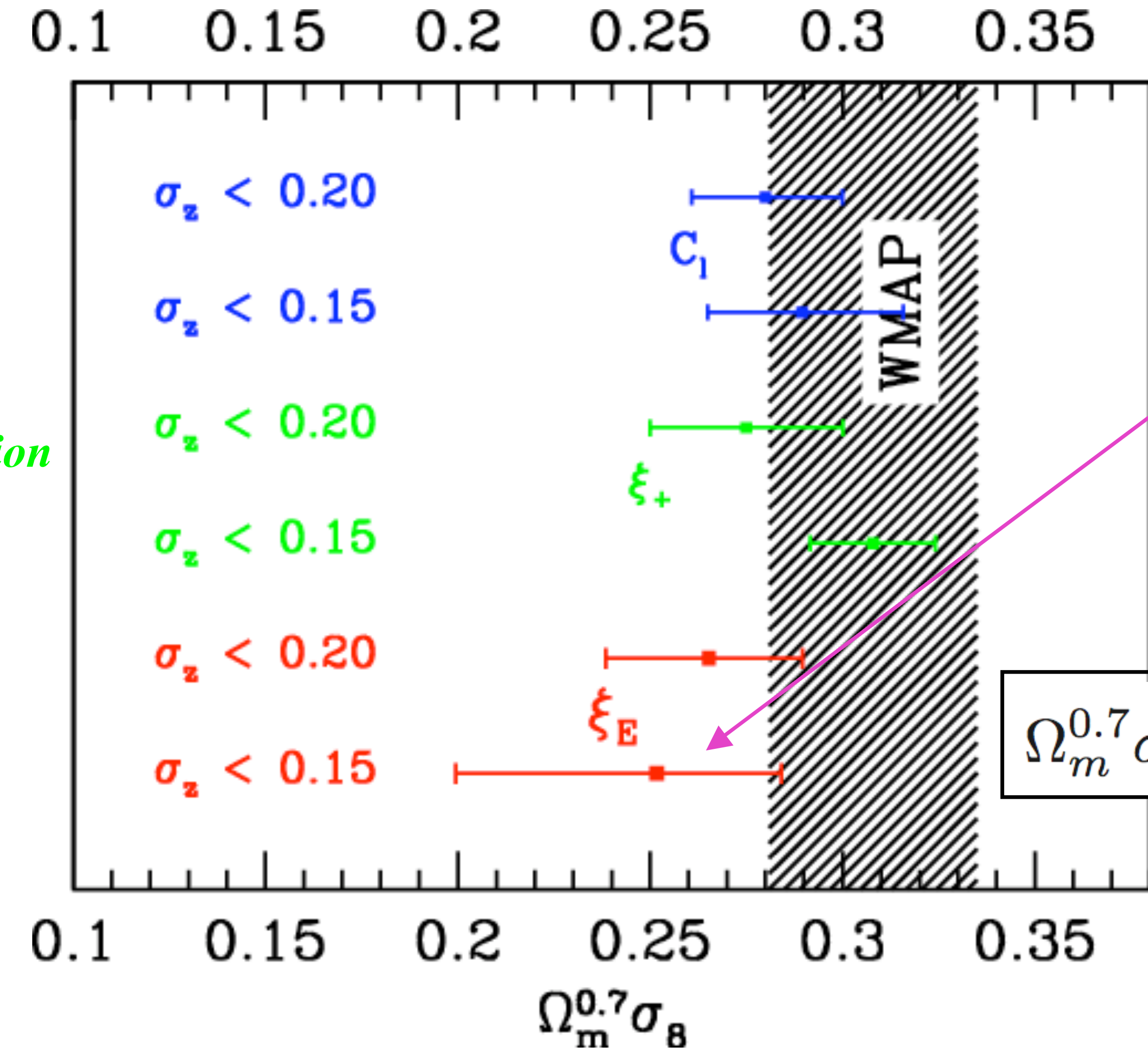


Cosmology constraints

Power spectrum

ξ_+ correlation function

ξ_E E-mode correlation function

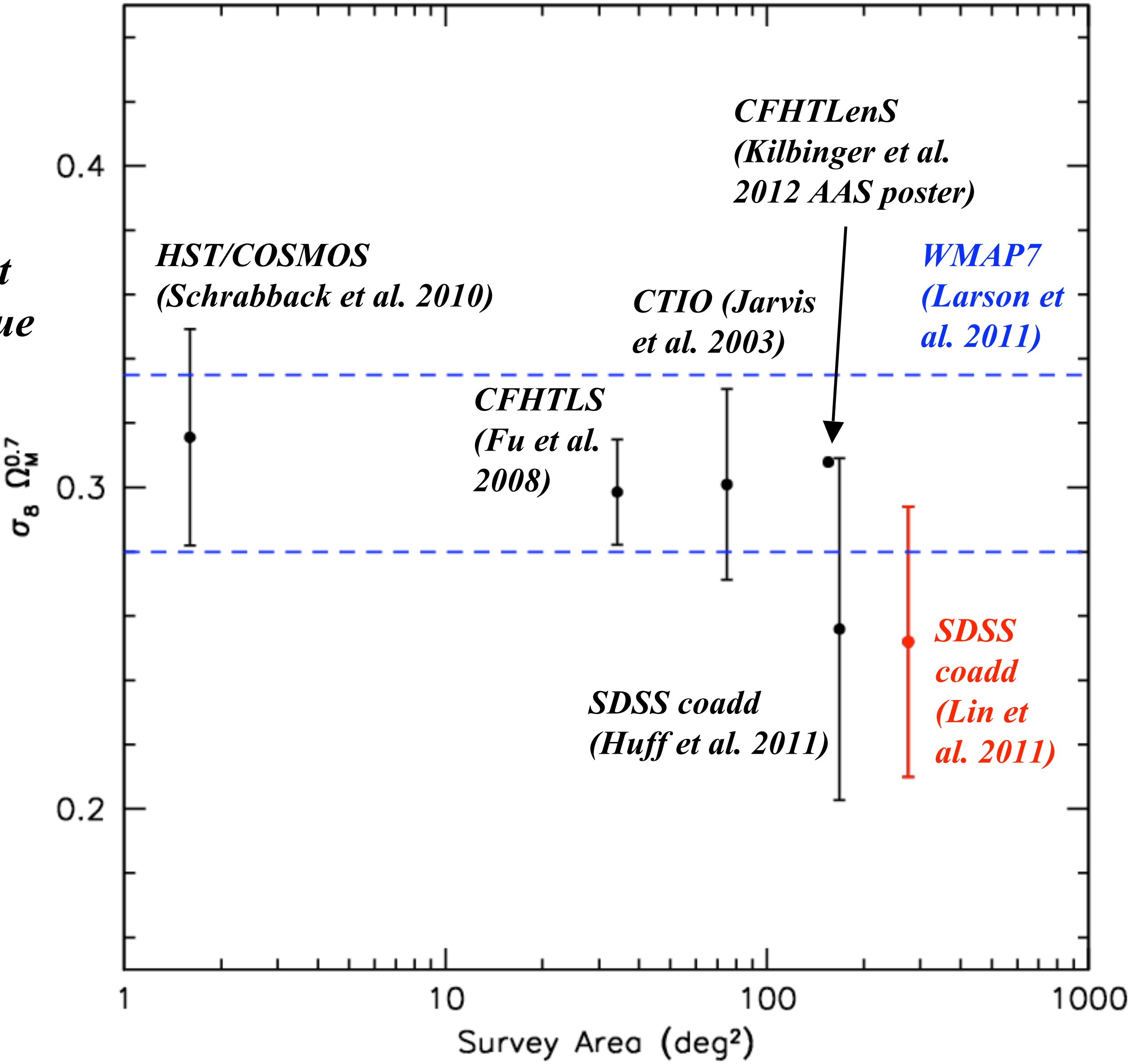


Final result uses our most conservative method/sample (in terms of error bar, photo-z errors, and B-modes):

$$\Omega_m^{0.7}\sigma_8 = 0.252^{+0.032}_{-0.052}$$

Cosmology constraint vs. survey area

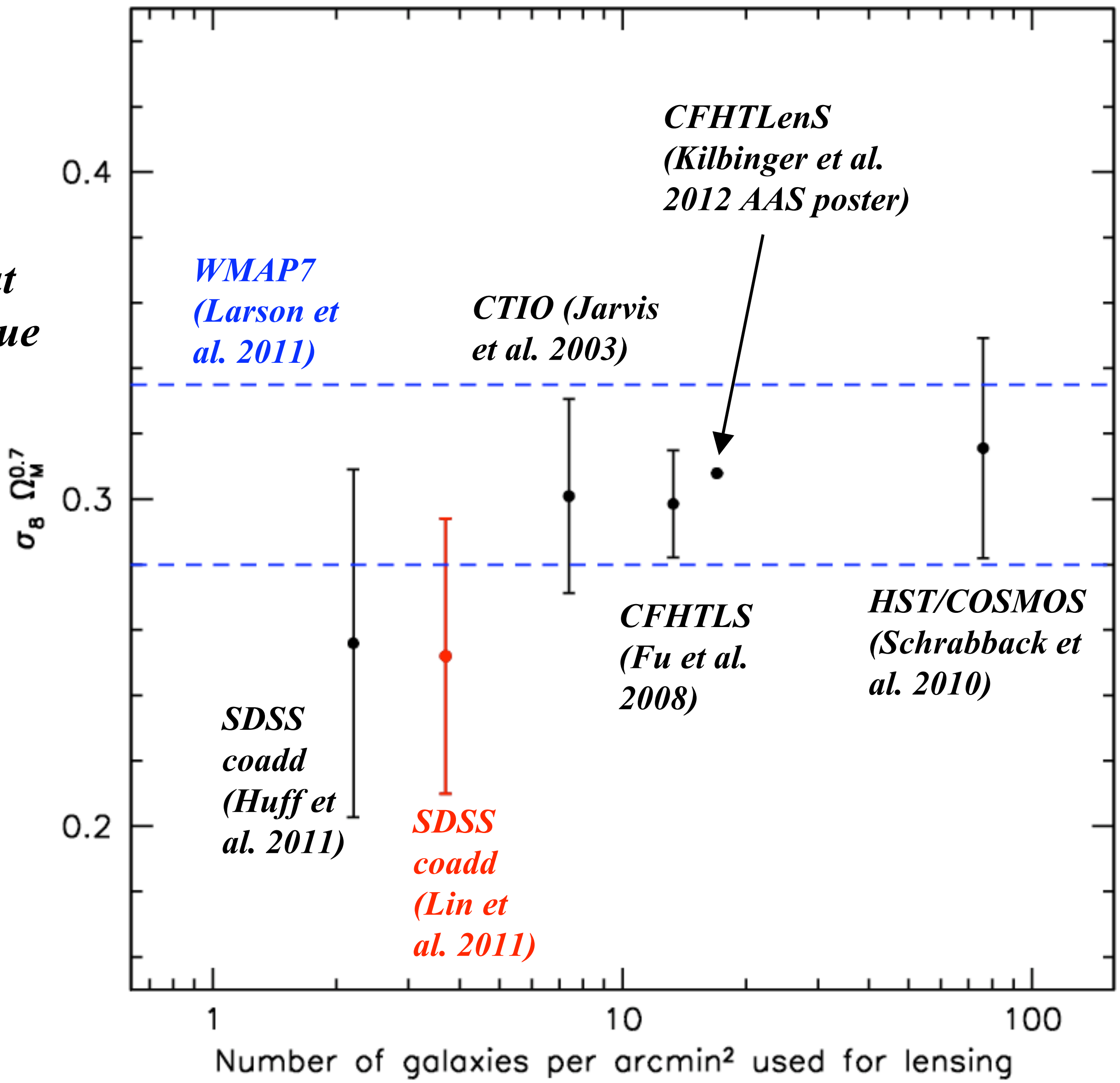
$\sigma_8\ \Omega_M^{0.7}$ evaluated at WMAP value $\Omega_M = 0.266$



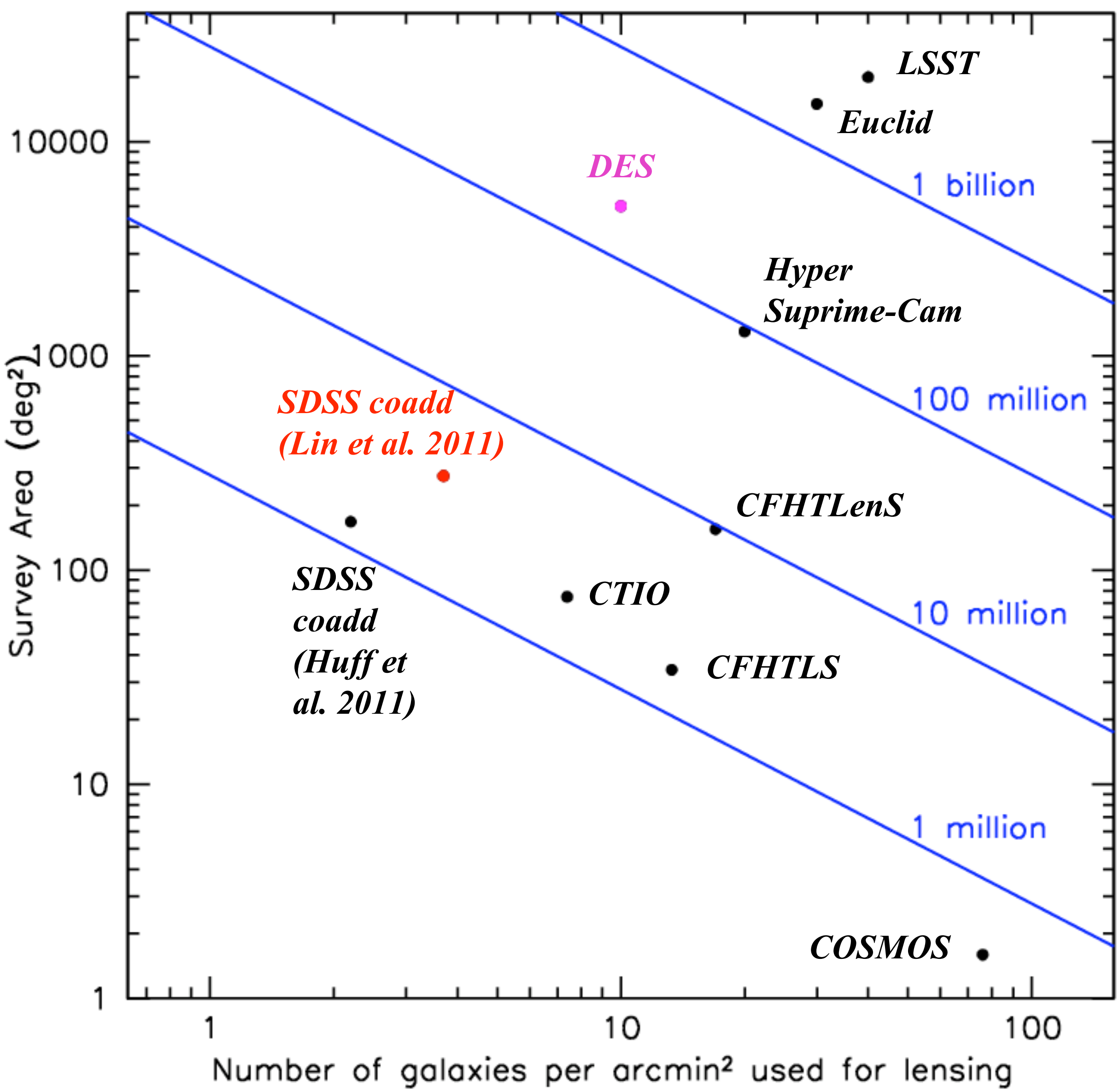
At 275 deg², we are the largest area survey used for cosmic shear detection so far

Cosmology constraint vs. N_{eff}

$\sigma_8\ \Omega_M^{0.7}$ evaluated at WMAP value $\Omega_M = 0.266$



Survey area vs. N_{eff}



Blue lines indicate constant numbers of galaxies

The Dark Energy Survey

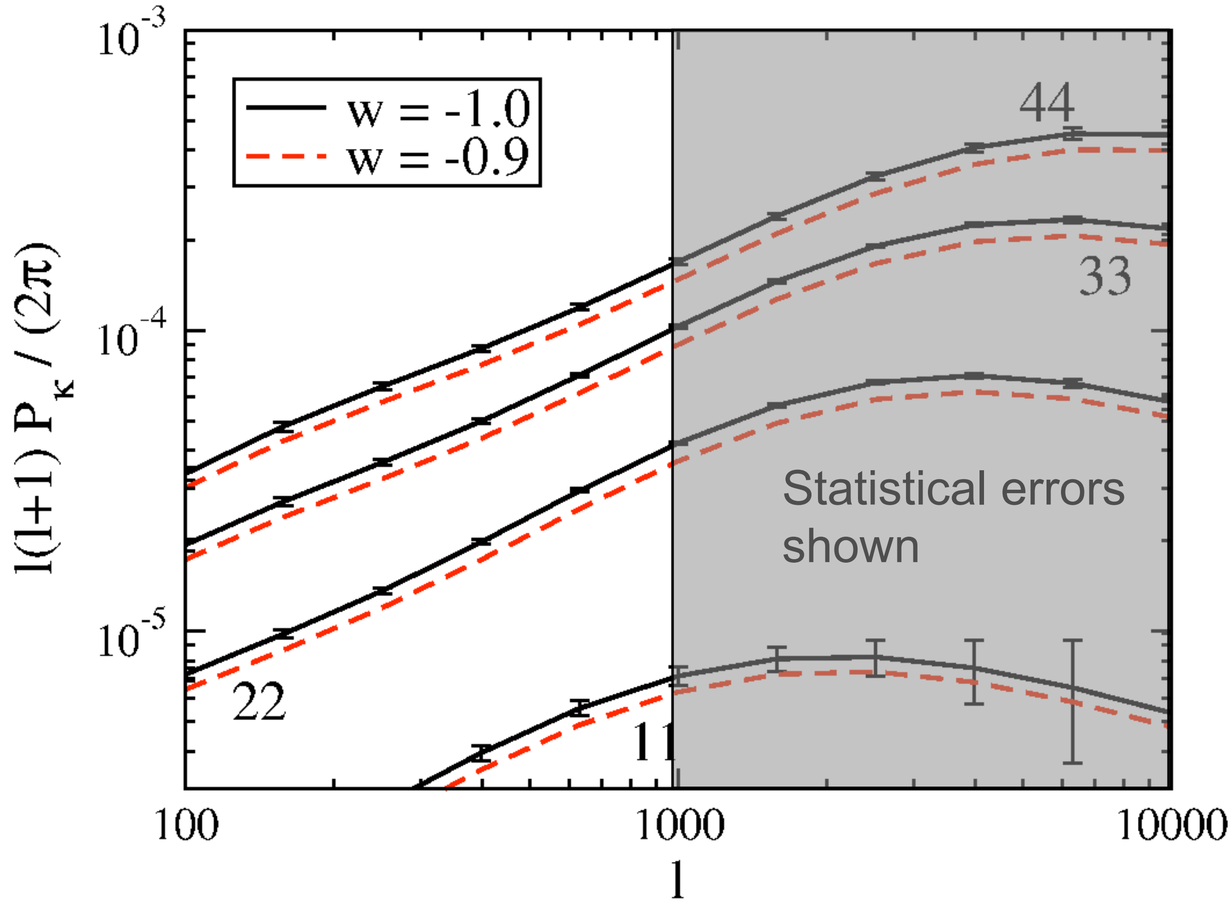
- Survey project using 4 complementary techniques:
  - I. Cluster Counts
  - II. Weak Lensing
  - III. Large-scale Structure
  - IV. Supernovae
- Two multiband surveys:
  - 5000 deg^2 *grizY* to 24th mag
  - 30 deg^2 repeat (SNe)
- Build new 3 deg^2 FOV camera and Data management system
  - Survey 2012-2017 (525 nights)
  - Facility instrument for Blanco

Blanco 4-meter at CTIO

II. Weak Lensing Tomography

DARK ENERGY SURVEY

- Cosmic Shear Angular Power Spectrum in Photo-z Slices
- Shapes of ~300 million well-resolved galaxies, $\langle z \rangle = 0.7$
- Primary Systematics: photo-z's, PSF anisotropy, shear calibration
- Extra info in bispectrum & galaxy-shear: robust



DES WL forecasts conservatively assume 0.9" PSF = median *delivered* to existing Blanco camera: DECam should do better & be more stable

From J. Frieman

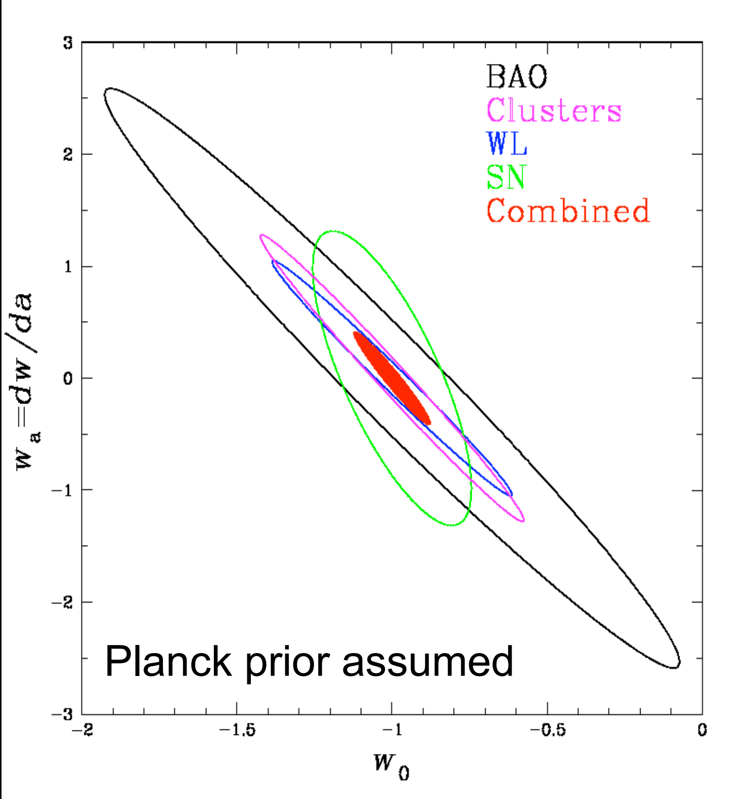
DES Science Summary

DARK ENERGY SURVEY

Four Probes of Dark Energy

- Galaxy Clusters
  - ~100,000 clusters to z>1
  - Synergy with SPT
  - Sensitive to growth of structure and geometry
- Weak Lensing
  - Shape measurements of 300 million galaxies
  - Sensitive to growth of structure and geometry
- Baryon Acoustic Oscillations
  - 300 million galaxies to z = 1 and beyond
  - Sensitive to geometry
- Supernovae
  - 30 sq deg time-domain survey
  - ~4000 well-sampled SNe Ia to z ~1
  - Sensitive to geometry

Forecast Constraints on DE Equation of State



Factor 3-5 improvement over Stage II DETF Figure of Merit

 From J. Frieman

Conclusions

- Four papers based on SDSS coadd: data, photometric redshifts, cluster lensing, cosmic shear
- Largest area (275 deg^2) survey for which cosmic shear has been detected
- Consistent cosmic shear results using both correlation function and power spectrum analyses
- Cosmology constraint $\Omega_m^{0.7}\sigma_8 = 0.252^{+0.032}_{-0.052}$
  - Consistent with WMAP 7-year results, but favors slightly lower matter density and clustering amplitude
- Looking forward to further lensing analyses using coadd and using early DES data, expected later this year